Noninvasive monitoring of end-tidal CO\textsubscript{2} via nasal cannulas in spontaneously breathing children during the perioperative period

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Objective: To determine the correlation between end-tidal CO\textsubscript{2} and Paco\textsubscript{2} values measured via nasal cannulas in spontaneously breathing children during the perioperative period.

Design: Prospective evaluation.

Setting: Pediatric intensive/intermediate care unit in a tertiary care referral center.

Patients: Thirty postoperative surgical and trauma patients aged ≤18 yrs (average age 7.8 yrs [range 6 months to 16 yrs]) and average weight 28.3 kg (range 8.5 to 69).

Measurements and Main Results: Spontaneously breathing, nonintubated patients with an arterial cannula in place were selected for study. End-tidal CO\textsubscript{2} was sampled from nasal cannulas by a sidestream aspirator and was estimated by infrared spectroscopy. The difference between Paco\textsubscript{2} and end-tidal CO\textsubscript{2} was compared using linear regression analysis. A total of 55 blood gas measurements were obtained on the 30 patients. The Paco\textsubscript{2} to end-tidal CO\textsubscript{2} gradient was ≤4 torr in 54 of the 55 samples. The mean Paco\textsubscript{2} was 39.5 ± 3.3 torr (5.27 ± 0.44 kPa) with a mean end-tidal CO\textsubscript{2} value of 39.7 ± 3.8 torr (5.29 ± 0.51 kPa). Linear regression analysis of arterial vs. end-tidal CO\textsubscript{2} yielded a slope of 0.992 and p = .0001.

Conclusions: End-tidal CO\textsubscript{2} measurement by infrared spectroscopy provided an accurate estimation of Paco\textsubscript{2} in this patient population. Its use may limit the need for invasive monitoring and/or repeated arterial blood gas analysis. (Crit Care Med 1994; 22:1805–1808)

Key Words: carbon dioxide; capnometry; monitoring, physiologic; intensive care unit, pediatric; blood gas analysis; spectroscopy, infrared; linear regression; cannulation, nasal; lungs; critical illness

The monitoring of end-tidal CO\textsubscript{2} has become a standard of care to ensure patient safety during anesthetic care. The technique documents the adequacy of ventilation and may limit the need and also the cost of invasive procedures such as arterial blood gas analysis. The results from two previous studies (1, 2) in adults suggest that end-tidal CO\textsubscript{2} may be accurately measured via nasal cannulas during spontaneous ventilation. Experience with this technique in the pediatric population is limited (3); therefore, we undertook a prospective evaluation of the accuracy of end-tidal CO\textsubscript{2} in a group of spontaneously breathing children without an artificial airway during the perioperative period.

MATERIALS AND METHODS

This study was approved by the Institutional Review Board and the Committee for the Protection of Human Subjects of Vanderbilt University. Written consent was not deemed necessary. The patient population included postoperative and trauma patients admitted to either the pediatric intensive or intermediate care units. Spontaneously breathing, nonintubated patients with an arterial cannula in place were selected for study. A total of 30 children were included in the study, ranging in age from 6 months to 16 yrs (mean 7.8 yrs) and in weight from 8.5 to 69 kg (mean 28.3). The admitting diagnoses included spinal fusion (n = 12), craniotomy (n = 6), craniofacial reconstruction (n = 5), multiple trauma (n = 4), laparotomy (n = 2), and pneumonectomy (n = 1).

End-tidal CO\textsubscript{2} was sampled through a nasal cannula that was attached to the patient. To avoid discrepancies in sampling that might occur from oxygen delivery, special nasal cannulas (Salter Labs, Arvin, CA)
were used. The two prongs of these cannulas are separated so that oxygen can be delivered through one side and CO₂ can be sampled through the other (Fig. 1). Once the cannulas were in place, supplemental oxygen was delivered through one prong of the cannula, as needed, to maintain oxygen saturation in an acceptable range.

End-tidal CO₂ was measured by infrared spectroscopy (SaraCap, PPG Biomedical Systems, Lenexa, KS) with a sidestream aspirator which has a flow rate of 180 mL/min. When clinically indicated, arterial blood gas measurements were obtained. At that time, the end-tidal CO₂ was monitored for 15 secs and the average of the values taken as the end-tidal CO₂. The digital readout of the end-tidal CO₂ on the spectroscopic was based on an algorithm that evaluates two successive waveforms and the valley between them. The end-tidal CO₂ reported by the monitor is the maximum value achieved on the first waveform. Arterial blood gases were measured at 37°C, but corrected to the patient's temperature. In addition to calculating mean values for the samples of end-tidal CO₂ and Paco₂, the arterial to end-tidal gradient was determined. In certain cases, the end-tidal concentration exceeded the Paco₂, thereby resulting in a negative value. Therefore, when the mean was calculated, this value did not give a true reflection of the difference in the two values (Paco₂ and end-tidal CO₂). We felt that a more accurate representation of the data was achieved by calculating a mean for the absolute difference and eliminating the use of negative values.

For example, if the end-tidal CO₂ was 42 torr (5.6 kPa) and the Paco₂ was 40 torr (5.33 kPa), the value for determining the mean was 2 and not −2 torr (0.27 kPa).

The correlation between end-tidal CO₂ and Paco₂ was analyzed by linear regression. All values are reported as mean ± SD with p < .05 considered significant.

RESULTS

A total of 55 samples were drawn on the 30 study patients. The mean Paco₂ was 39.5 ± 3.3 torr (5.27 ± 0.44 kPa) with a mean end-tidal CO₂ concentration of 39.7 ± 3.8 torr (5.29 ± 0.51 kPa). The Paco₂ to end-tidal CO₂ gradient was ≤4 torr in 54 of the 55 samples. One patient had a single value with a difference of 9.1 torr (1.21 kPa). The mean absolute difference was 2.2 ± 0.9 torr (0.29 ± 0.12 kPa). The linear regression analysis of end-tidal CO₂ and Paco₂ resulted in a slope of 0.992, an $r^2 = .804$, and $p = .0001$ (Fig. 2).

DISCUSSION

We demonstrated that end-tidal CO₂ measured via nasal cannulas correlates with Paco₂ during spontaneous ventilation in children. This accuracy was constant through a wide range of ages, weights, and respiratory rates. Although previous studies (4, 5) demonstrated the correlation between end-tidal CO₂ and

![Figure 1. Representation of the nasal cannulas used in the study. The two prongs are separated so that oxygen can be delivered through one side and CO₂ can be sampled through the other.](image)

![Figure 2. Linear regression curve of end-tidal CO₂ and Paco₂. Each set of values is represented by a single point with values of both end-tidal CO₂ and Paco₂ expressed in torr (25 torr = 3.33 kPa). A total of 55 sample sets are included, although many of the sample points are superimposed on one another. Linear regression analysis of end-tidal CO₂ and Paco₂ resulted in a slope of 0.992 and an $r^2 = .804$ (p = .0001).](image)
They included intubated and mechanically ventilated patients. Our preliminary data suggest the accuracy of this correlation in the pediatric population during spontaneous ventilation without an artificial airway.

Methods used to estimate end-tidal CO₂ vary in the equipment used to measure CO₂ content and the sampling site. Sampling includes either side-arm aspiration or a mainstream capnometer. With the latter, a cuvette containing the sensor is placed between the endotracheal tube and the breathing circuit. Although this method provides a relatively reliable estimation of end-tidal CO₂, its application to nonintubated patients is limited. With the sidestream aspirating devices, the sensor is located a distance from the patient and the sample is aspirated from the patient’s airway and carried to the sensor through small-bore tubing. Various adaptations of this device have been used to measure end-tidal CO₂ in patients without an artificial airway (1, 5).

The methods used to measure end-tidal CO₂ include mass spectroscopy, Raman spectroscopy, infrared spectroscopy, and photoacoustic spectroscopy. The technology of this equipment has been reviewed (6). Because of its compact nature and cost when compared with the other methods, infrared spectroscopy remains the most popular method currently used. Infrared waves are absorbed by nonelementary gases such as CO₂ with the amount of light absorbed being proportional to the concentration of gas. Therefore, by passing an infrared light through the gas and comparing it to a known standard, the CO₂ concentration can be estimated.

Although we demonstrated the correlation between Paco₂ and end-tidal CO₂ in our patient population, several factors may interfere with the accuracy of this monitoring. These factors include both sampling error and alterations in the ventilation-perfusion status of the respiratory system. Sampling error may occur during several situations including hypoventilation, mouth breathing, or low tidal volumes. These situations lead to low flow rates through the nasal prong which may allow the entrainment of room air and a false low end-tidal CO₂ reading. Aside from occasional blockage of the nasal cannula or sampling tubing with mucus, we did not encounter other problems in our patient population using a flow rate of 150 mL/min in patients weighing as little as 8.5 kg and with respiratory rates up to 36 breaths/min.

Aside from sampling errors, alterations in the cardiorespiratory status of the patient may influence the correlation between Paco₂ and end-tidal CO₂ (7). These alterations include factors that increase the ventilation-perfusion ratio, leading to an increase in deadspace. Deadspace refers to those units of the lung that do not participate in gas exchange. The total or physiologic deadspace comprises both the conducting Airways (anatomic deadspace) and those areas of the lung that have high ventilation/perfusion ratios (alveolar deadspace). In such segments, the end-tidal CO₂ to Paco₂ difference increases. As these segments empty, they dilute out other segments with normal ventilation/perfusion ratios leading to an increase in the total ratio. An increase in the ventilation/perfusion ratio may occur with either a relative increase in ventilation or a decrease in perfusion. Such alterations occur with the institution of positive pressure ventilation (8), acute pulmonary embolism (9), changes in position (standing to lying, supine to lateral decubitus [10]), and a decrease in cardiac output. Therefore, the accuracy of end-tidal CO₂ monitoring may be limited in these situations which may be present in the pediatric intensive care unit (ICU) population.

The reverse situation (i.e., shunt) also commonly occurs in the pediatric ICU patient. In these areas, there is blood flow with little or no ventilation. Although these areas do not directly affect alveolar CO₂ concentrations, the admixture of this blood into the arterial system increases Paco₂ thereby widening the end-tidal CO₂ to Paco₂ gradient. The magnitude of its effect is dependent on the amount of shunt. The end-tidal CO₂ to Paco₂ difference can be used to estimate shunt fraction and deadspace ventilation (11). Because of these concerns, we decided to limit our initial investigation to the current group of patients who had little or no parenchymal lung disease and who had stable cardiovascular function.

Despite these concerns, end-tidal CO₂ measurement may prove to be a useful adjunct to the monitoring of certain patient groups in the pediatric ICU. We found it to be an accurate and reliable means of estimating Paco₂ in the perioperative period in patients without underlying pulmonary parenchymal diseases or alterations in cardiovascular function. The range of Paco₂ in our patients varied from 30 to 48 torr (4 to 6.4 kPa), and therefore, we cannot comment on its accuracy with extreme values of Paco₂. Future studies are needed to define its role in other patient populations.

With these restrictions in mind, end-tidal CO₂ monitoring may limit the need for invasive measurement of Paco₂ thereby limiting patient cost. At our institution, the cost for end-tidal CO₂ monitoring includes an initial set-up fee (one-time charge) of $68.54 followed by a daily fee of $15.54 while a single blood gas analysis is $74.00. Additionally, the use of this noninvasive technique may limit repeated phlebotomy and iatrogenic anemia.
REFERENCES


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