Transcutaneous carbon dioxide monitoring: Applications in the operating room

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The intraoperative monitoring of the partial pressure of carbon dioxide in arterial blood (pCO_2) is used to assess the adequacy of ventilation and guide clinical interventions.

Although end-tidal CO_2 monitoring remains the most frequently used non-invasive technology in the intraoperative setting to provide a continuous estimate of pCO_2, given its potential for inaccuracy with alterations in pulmonary function, there is a continued need for other non-invasive means of monitoring pCO_2.

Although transcutaneous (TC) CO_2 monitoring has been used in the ICU setting, there are little data regarding its use in the intraoperative setting. This manuscript reviews the reports regarding the intraoperative applications of TC-CO_2 monitoring and discusses the potential intraoperative applications of this non-invasive monitoring modality.

Introduction

The monitoring of the partial pressure of carbon dioxide (pCO_2) in the arterial blood is used to assess the adequacy of ventilation during both spontaneous and controlled ventilation.

Although the gold standard for monitoring pCO_2 remains intermittent arterial blood gas (ABG) analysis, ABGs provide only an intermittent sample of what is often a dynamic and rapidly changing value. To overcome such problems, non-invasive monitors are used both in the ICU and intraoperatively to provide a continuous estimate of pCO_2.

Routine monitoring in the operating room includes end-tidal CO_2 (ET-CO_2) measurement; however, several patient-related issues such as ventilation-perfusion mismatch may influence the correlation of the ET-CO_2 with pCO_2 [1, 2]. Grenier *et al* have demonstrated that there is a significant influence of patient positioning on the correlation between ET-CO_2 and pCO_2 as well as a significant variation or instability of the gradient over time, thereby questioning the utility of ET-CO_2 monitoring during neurosurgical procedures [3].

Transcutaneous (TC) CO_2 devices provide another option for the continuous, non-invasive estimation of pCO_2. Although these devices have been shown to be accurate in infants, children, and adolescents in the Neonatal or Pediatric ICU setting [4, 5], there remains limited information regarding the intraoperative applications of TC-CO_2 monitoring.

Intraoperative applications - adults

Because of its effects on cerebral blood flow and intracranial pressure, the intraoperative control of pCO_2 can be of great significance during neurosurgical procedures. Given the inherent inaccuracies noted in the study of Grenier *et al* [3] and the importance of monitoring pCO_2 during neurosurgical procedures, we carried out a prospective study to determine the accuracy of ET- and TC-CO_2 monitoring during neurosurgical procedures in adults [6].

The patient population included patients 18 years of age or older presenting for neurosurgical procedures in which intra-arterial access was deemed necessary by the attending anesthesiologist. ET-CO_2 was measured using standard intraoperative, infrared spectroscopy with a sidestream aspirator connected at the elbow between the endotracheal tube (ETT) and the anesthesia circuit.

Prior to placement, the electrode was cleaned, a new membrane applied, and calibration performed according to the manufacturer's recommendations. The working temperature of the electrode was set at 45 °C.

ABGs were obtained as clinically indicated during the surgical procedure and compared to the values from the two non-invasive monitors. The cohort for the study included 30 adults ranging in age from 18 to 76 years and in weight from 49 to 130 kilograms undergoing a craniotomy for various indications.

No patient was receiving an inotropic agent or adrenergic agonist. None of the patients had significant tissue edema or manifested signs of a low cardiac output state. Fifty-seven sample sets (pCO_2, ET-CO_2, and TC-CO_2) were obtained from the 30 patients, **Fig. 1**.

The actual pCO_2 ranged from 26 to 62 mmHg. The ET-CO_2-to-pCO_2 difference was 6.1 ± 5.6 mmHg, while the TC-CO_2-to-pCO_2 difference was 3.7 ± 2.9 mmHg (p=0.005).

The difference between the pCO_2 and ET-CO_2 was 3 mmHg or less in 17 of 57 values, while the difference between the pCO_2 and TC-CO_2 was 3 mmHg or less in 35 of 57 values (p = 0.002, odds ratio of 3.942). The difference between the pCO_2 and ET-CO_2 was 5 mmHg or less in 31 of 57 values, while the difference between the pCO_2 and TC-CO_2 was 5 mmHg or less in 47 of 57 values (p = 0.00139, odds ratio of 3.743).

Linear regression analysis of ET-CO_2 versus pCO_2 revealed a slope of 0.381, r value = 0.5531, and r^2 = 0.3025. Linear regression analysis of TC-CO_2 versus pCO_2 revealed a slope of 1.17, r value = 0.8824, and r^2 = 0.7786.

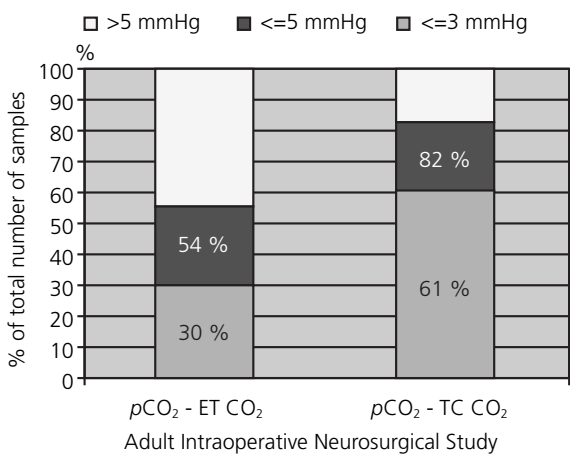

FIG. 1. Difference in pCO_2 (ABG) in relation to TC and ET grouped by ≤3 mmHg; ≤5 mmHg and > 5 mmHg (n = 57).

Intraoperative applications – infants and children

ET-CO_2 monitoring may also be notoriously inaccurate in infants and smaller children given their smaller tidal volumes and additional problems imposed by the type of mechanical ventilator used (continuous versus intermittent gas flow) and the site of ET-CO_2 monitoring (distal or proximal end of the ETT) [7, 8]. The latter is true regardless of the clinical scenario (Pediatric/Neonatal ICU or intraoperative care).

We carried out a prospective study to determine the accuracy of ET- and TC-CO_2 monitoring during intraoperative care in infants and children [9]. The patient population included patients 18 years of age or younger for whom intra-arterial access was deemed necessary by the attending anesthesiologist. ET- and TC-CO_2 were measured as in our previously described intraoperative study (see above).

The cohort for the study included 30 patients ranging in age from 6 months to 15 years and in weight from 4.7 to 73 kilograms. Sixty-four sample sets (pCO_2, ET-CO_2, and TC-CO_2) were obtained from the 30 patients. The ET-CO_2-to-pCO_2 difference was 4.4 ± 7.1 mmHg, while the TC-CO_2-to-pCO_2 difference was 2.8 ± 2.9 mmHg.

The difference between the pCO_2 and ET-CO_2 was 3 mmHg or less in 37 of 64 values, while the difference between the pCO_2 and TC-CO_2 was 3 mmHg or less in 49 of 64 values ($p<0.05$). The difference between the pCO_2 and ET-CO_2 was 5 mmHg or less in 55 of 64 values, while the difference between the pCO_2 and TC-CO_2 was 5 mmHg or less in 62 of 64 values. (**Fig. 2**.).

Linear regression analysis of ET-CO_2 versus pCO_2 revealed a slope of 0.434 ± 0.007, r value = 0.8761, and r^2 = 0.7676, while linear regression analysis of TC-CO_2 versus pCO_2 revealed a slope of 0.914, r value = 0.9140, and r^2 = 0.8972.

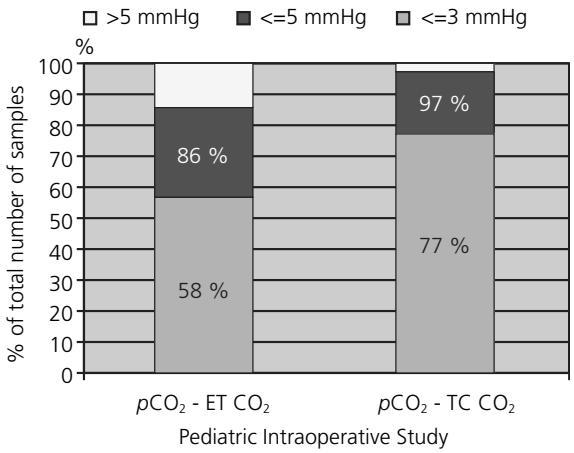

Fig. 2. Difference in pCO_2 (ABG) in relation to TC and ET grouped by ≤3 mmHg; ≤5 mmHg and > 5 mmHg (n = 64).

The true utility of TC-CO_2 monitoring is demonstrated by one of the patients in the current study who developed intraoperative bronchospasm. Despite an ET-CO_2 of only 70 mmHg, the TC-CO_2 was reading 110 mmHg with a pCO_2 that was 122 mmHg.

Discussion

Since its inception, TC-CO_2 monitoring has received the greatest use in the neonatal population. Previous studies have also validated the accuracy of TC-CO_2 monitoring in the Pediatric ICU population with respiratory failure of various etiologies and following cardiothoracic surgical procedures [4, 5].

In these studies, TC-CO_2 monitoring proved especially efficacious in settings where ventilation-perfusion disturbances or other patient factors can be expected to interfere with the gradient between the ET and pCO_2 [24, 5].

Intraoperative monitoring

We have also found that intraoperative TC-CO_2 monitoring can be a clinically useful adjunct to standard intraoperative monitoring techniques. As outlined above in our two intraoperative studies, we noted, in both clinical intraoperative scenarios (adult and pediatric patients), that TC-CO_2 monitoring was more accurate and provided a closer estimation of pCO_2 than ET-CO_2 monitoring.

To date, there remains limited other information concerning intraoperative TC-CO_2 monitoring. Bhavani-Shankar *et al* reported the use of TC-CO_2 during intraoperative anesthetic care for a laparoscopic cholecystectomy in a parturient [10].

Their use of TC-CO_2 monitoring was prompted by reports of the potential problems with ET-CO_2 monitoring during laparoscopy. Since there was no indication for placement of an indwelling arterial catheter and since there was a limited increase in the TC-CO_2, ABG analysis was not performed.

The authors noted an increase in the TC-CO_2 from a baseline of 39.1 ± 0.1 mmHg to a maximum of 45.7 ± 0.1 mmHg as well as an increase in the TC-to-ET gradient from 6.6 ± 0.3 mmHg to 13.7 ± 0.2 mmHg during peritoneal insufflation with CO_2.

Reid et al compared ET- with TC-CO_2 monitoring during general anesthesia in 22 adults during 3 different levels of mechanical ventilation [11].

A total of 66 data sets with the pCO_2 ranging from 28 to 62 mmHg demonstrated an ET-to-arterial gradient of 7.0 ± 3.1 mmHg with a correlation coefficient of r = 0.89 and a TC-to-arterial gradient of 2.3 ± 2.4 mmHg ($p < 0.05$ when compared to TC-to-arterial gradient) with r = 0.92. The differences were greatest at the higher pCO_2 values.

Phan *et al* also compared ET- and TC-CO_2 monitoring during general anesthesia in 24 adults [12]. The correlation coefficient, bias, and precision for the ET-to-arterial comparison were 0.67, –7.8 mmHg, and ± 6.1 mmHg, while the correlation coefficient, bias, and precision for the TC-to-arterial comparison were 0.87, –1.6 mmHg, and ± 4.3 mmHg.

By following some important caveats and technical suggestions, we have found that TC-CO_2 monitoring will provide an excellent and clinically acceptable estimate of pCO_2, which we have found is better than that obtained with conventional, intraoperative ET-CO_2 monitoring.

When reviewing the literature concerning TC-CO_2 monitoring, the type and manufacturer of the monitor and whether a "calibration factor" is used by the monitor can affect the accuracy of the monitoring and thereby the results of the study. Regardless of the monitor used, the tissue CO_2 and therefore the TC-CO_2 is invariably higher than the pCO_2 unlike the ET-CO_2, which is invariably lower than the pCO_2.

Technical aspects of TC monitoring – temperature corrections

The TC-CO_2 monitor used in our intraoperative studies, corrects for the alterations in CO_2 caused by heating the skin to 43-45 °C. Heating of the skin is necessary to ensure capillary vasodilatation and an equilibration between the tissue and capillary pCO_2.

With heating of the skin, the uncorrected TC-CO_2 is significantly above the pCO_2 (measured at 37 °C) because of increased CO_2 production from the elevated local tissue metabolism and the altered solubility of CO_2 at higher temperatures.

The importance of these factors is illustrated by the study of Tremper *et al* [13]. The authors, without correcting the TC-CO_2 value for temperature differences, compared the transcutaneous and arterial values of CO_2 in 435 data sets in 44 patients in a mixed OR/ICU setting [8].

Although they noted a wide difference between the TC and the CO_2 value (23 ± 11 mmHg), linear regression analysis yielded a correlation coefficient of 0.80. They also noted that, with a low cardiac output state (cardiac index less than 1.5 L/min/m^2), there was a further increase in the TC-to-arterial CO_2 gradient and the TC-CO_2 trended inversely with the cardiac index and not the pCO_2.

A similar effect of cardiovascular performance and the gradient between arterial and TC carbon dioxide has been reported by other investigators [14-17]. No patient in either of our intraoperative studies manifested clinical signs or symptoms of cardiovascular dysfunction or a low cardiac output state.

Technical aspects of TC monitoring – preparation time

When compared with ET-CO_2 monitoring, TC-CO_2 monitoring requires a much longer preparation time including a 5-minute calibration period prior to placement and then an additional 10- to 15-minute equilibration period after placement on the patient to allow for an equilibration between the TC and arterial CO_2 values.

Once the electrode is placed, recalibration and replacement at another site every 4 hours is recommended by the manufacturer, making this monitor more labor intensive than ET-CO_2 monitoring. This may be problematic if access is limited to the patient intraoperatively when replacement at another site is needed due to the duration of the surgical procedure.

Technical aspects of TC monitoring – others

Although we found that TC-CO_2 monitoring provided a more accurate reflection of pCO_2 in most patients, several factors related to the monitor itself may affect this accuracy including technical variables such as trapped air bubbles, improper placement technique, damaged membranes, and inappropriate calibration techniques. In addition to technical problems, patient problems may affect the accuracy of TC-CO_2 monitoring.

These may include variations in skin thickness, the presence of edema, tissue hypoperfusion, or the administration of vasoconstricting drugs [4, 14-17]. Following our clinical experience, we would recommend keeping the working temperature of the probe at 44-45 °C. As this can leave a superficial blister, we always warn the patient of this preoperatively and change the site every 2.5 to 3 hours.

Our clinical experience also suggests that more accurate readings are provided when the probe is placed over specific areas of the body such as the ventral (volar) aspect of the forearm.

Conclusion

Because no technique can be expected to be 100 % reliable, periodic calibration with pCO_2 values is recommended.

In our clinical experience, although TC-CO_2 monitoring is a more accurate means of estimating pCO_2, ET-CO_2 is still required during intraoperative care as it documents the intratracheal position of the endotracheal tube and serves as an additional safety monitor to alert one to a ventilator disconnection, functions not provided by ET-CO_2 monitoring.

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