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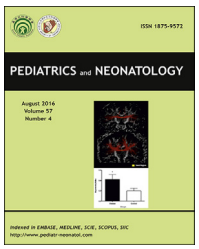

Original Article

Application of end-tidal carbon dioxide monitoring via distal gas samples in ventilated neonates

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Key Words
arterial partial pressure of carbon dioxide;
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neonate

Background: Previous research has suggested correlations between the end-tidal partial pressure of carbon dioxide ($P_{ET}CO_2$) and the partial pressure of arterial carbon dioxide ($PaCO_2$) in mechanically ventilated patients, but both the relationship between $P_{ET}CO_2$ and $PaCO_2$ and whether $P_{ET}CO_2$ accurately reflects $PaCO_2$ in neonates and infants are still controversial. This study evaluated remote sampling of $P_{ET}CO_2$ via an epidural catheter within an endotracheal tube to determine the procedure's clinical safety and efficacy in the perioperative management of neonates.

Methods: Abdominal surgery was performed under general anesthesia in 86 full-term newborns (age 1–30 days, weight 2.55–4.0 kg, American Society of Anesthesiologists class I or II). The infants were divided into 2 groups (n = 43 each), and carbon dioxide (CO_2) gas samples were collected either from the conventional position (the proximal end) or a modified position (the distal end) of the epidural catheter.

Results: The $P_{ET}CO_2$ measured with the new method was significantly higher than that measured with the traditional method, and the difference between $P_{ET}CO_2$ and $PaCO_2$ was also reduced. The accuracy of $P_{ET}CO_2$ measured increased from 78.7% to 91.5% when the modified sampling method was used. The moderate correlation between $P_{ET}CO_2$ and $PaCO_2$ by traditional measurement was 0.596, which significantly increased to 0.960 in the modified sampling group. Thus, the $P_{ET}CO_2$ value was closer to that of $PaCO_2$.

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Conclusion: $P_{ET}CO_2$ detected via modified carbon dioxide monitoring had a better accuracy and correlation with $PaCO_2$ in neonates.
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1. Introduction

During surgery to correct neonatal birth defects, mechanical ventilation usually is required following anesthesia, but perioperative cardiac arrest is associated with respiratory interventions in about one-third of neonatal patients.[1,2] Thus, the correct and rational use of mechanical ventilation in the perioperative period is crucial, and accurate evaluation of the effectiveness of mechanical ventilation in neonates requires frequent blood gas analysis during mechanical ventilation.[3] Arterial gas analysis is the gold standard for such measurements, but the procedure should be performed intermittently, is invasive and thereby increases the risk of infection, and may cause adverse events such as iatrogenic anemia.[4] Compared to the invasive and intermittent procedures for arterial gas analysis, monitoring of the end-tidal partial pressure of carbon dioxide ($P_{ET}CO_2$) is a continuous and noninvasive technique that is easy and straightforward to conduct. Thus, $P_{ET}CO_2$ has been regarded by the American Society of Anesthesiologists as a basic parameter that should be monitored during mechanical ventilation.[5]

In older children and adults, some studies have shown a correlation between $P_{ET}CO_2$ and the partial pressure of arterial carbon dioxide ($PaCO_2$).[6–11] Despite these reports, controversy exists regarding the relationship between $P_{ET}CO_2$ and $PaCO_2$ and whether $P_{ET}CO_2$ accurately reflects $PaCO_2$ in neonates and infants.[12–18] In infants who weigh >5 kg, a good correlation has been found between $P_{ET}CO_2$ and $PaCO_2$, and $P_{ET}CO_2$ can reflect $PaCO_2$. In infants who weigh <5 kg and in neonates, only a poor correlation has been identified between $P_{ET}CO_2$ and $PaCO_2$; $P_{ET}CO_2$ does not correlate with $PaCO_2$ levels; and the difference between $P_{ET}CO_2$ and $PaCO_2$ increases with body weight loss.[14–19] Some investigators have attempted to resolve these issues by sampling at different sites to measure $P_{ET}CO_2$ and have had some success in infants who weighed <12 kg.[20] Others conducted the sampling using a 22-gauge sampling needle at the middle of endotracheal tube[21] or used a double-lumen endotracheal tube for remote sampling; the latter significantly improved the correlation between $P_{ET}CO_2$ and $PaCO_2$ as well as the accuracy of the $P_{ET}CO_2$ measurement.[22] Even so, these techniques are suboptimal because of safety concerns and cannot be safely applied in clinical practice.

In the present study, a 1-mm (outer diameter) epidural catheter was used for gas sampling. An end was connected to the sampling tube, and the other end was inserted into the lateral hole at the top of endotracheal tube, which is different from traditional sampling at the proximal endotracheal tube to measure $P_{ET}CO_2$. With the new method, the catheter is placed close to the alveoli, which reduces the influence of dead space on the measurement of $P_{ET}CO_2$ and minimizes sample dilution by free gas.

2. Patients and methods

2.1. Patients

For this study we recruited a total of 86 full-term newborns aged 1–30 days who received elective surgery under general anesthesia to treat congenital pyloric obstruction, neonatal necrotizing enterocolitis, neonatal intestinal perforation, neonatal intestinal malrotation, or congenital aproctia. Patients' body weight ranged from 2.55 to 4.0 kg, and their American Society of Anesthesiologists class was I or II. There were no low-birth-weight babies, all had normal liver and kidney function, and none had infections, allergies, or hypoxia. Respiratory infections, concomitant cardiovascular or pulmonary deformities, and concomitant primary liver or renal diseases were not observed. Exclusion criteria included prematurity, low birth weight, respiratory infection, concomitant cardiovascular or pulmonary malformations, concomitant primary liver or renal disease, intraoperative severe hypotension or massive hemorrhage, or missing data. On the basis of a random number table, the selected newborns were randomly divided into 2 groups ($n = 43$ per group): in the traditional sampling group, routine sampling was performed; in the modified sampling group, modified sampling was employed. Patients' parents provided written informed consent, and the study protocol was reviewed and approved by the Ethics Committee of Zhejiang University School of Medicine.

2.2. Procedures

Before anesthesia, electrocardiogram, blood pressure, heart rate, and arterial oxygen saturation (SpO_2) were routinely measured, and venous access was established, followed by infusion of lactated Ringer's solution at 10–15 mL/kg/h. Oxygen was administered via a mask. Anesthesia was induced by intravenous injection of midazolam at 0.2 mg/kg, ketamine at 2 mg/kg, rocuronium bromide at 0.9 mg/kg, and fentanyl at 0.5 μg/kg. When muscular relaxation was observed, an endotracheal tube (3.0 or 3.5 mm) without balloon was inserted via the mouth, and symmetrical breath sounds suggested successful intubation. Mechanical ventilation was performed with a Dräger Primus anesthesia ventilator (Drägerwerk, Lübeck, Germany). A closed-circuit breather system was used in both groups, and intermittent positive pressure ventilation was performed with a tidal volume of 8–10 mL/kg, an inspiratory:expiratory ratio of 1:1.5–1:2, a respiratory rate of

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