Continuous end-tidal CO_2 sampling within the proximal endotracheal tube estimates arterial CO_2 tension in infants

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End-tidal CO_2 ($ETCO_2$) sampled using a 22-gauge needle inserted through the wall of the proximal endotracheal tube was compared with $ETCO_2$ obtained from the standard proximal connector to determine which was the more accurate sampling site for estimation of arterial CO_2 tension ($PaCO_2$). Fourteen infants were anaesthetized and their lungs ventilated using a Drager ventilator and a paediatric circle system. Blood gas determination of $PaCO_2$ was obtained from an arterial catheter and compared with continuous sampling of $ETCO_2$ analyzed by raman spectroscopy. The $PaCO_2$ (35.3 ± 4.9 mmHg, × ± SD) was not different from the $ETCO_2$ sampled within the proximal endotracheal tube (34.7 ± 3.8 mmHg), but was greater ($P < 0.05$) than the $ETCO_2$ at the proximal connector (31.6 ± 4.0 mmHg). We conclude that in infants during ventilation with a circle system, the $PaCO_2$ can be accurately assessed by continuous sampling of $ETCO_2$ from the proximal endotracheal tube.

Nous avons comparé les valeurs du CO_2 de fin d'expiration ($ETCO_2$) échantillonné soit au raccord du tube endotrachéal, soit à travers la paroi du bout proximal du même tube (avec une aiguille de calibre 22) et la $PaCO_2$ chez 14 bébés anesthésiés avec circuit fermé pédiatrique et ventilateur Drager. On mesurait le CO_2 expiré par spectroscopie de type raman et les gaz artériels. La $PaCO_2$ (35,3 ± 4,9 mmHg; valeur ± écart-type) était semblable au $ETCO_2$ échantillonné à travers la paroi du tube (34,7 ± 3,8 mmHg) mais supérieure à celui du raccord (31,6 ± 4,0 mmHg; $P < 0,05$). En circuit fermé et ventilation mécanique, la mesure continue du $ETCO_2$ prélevé dans le bout proximal du tube endotrachéal estime adéquatement la $PaCO_2$ des enfants de moins d'un an.

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Accurate $ETCO_2$ measurement is more difficult in infants than in adults because the relatively small tidal volume in conjunction with high fresh gas flows dilutes expired CO_2 leading to underestimation of $PaCO_2$.[1-4] To minimize the problem of expired gas dilution, Badgwell recommended sampling $ETCO_2$ from the distal tip of the endotracheal tube to assess accurately the $PaCO_2$ in infants and children.[5,6] Recently, Bissonette described a technique to estimate $PaCO_2$ accurately in children which may be simpler than distal sampling of $ETCO_2$.[7] Insertion of a needle through the wall of the proximal end of the endotracheal tube while the fresh gas flow was discontinued allowed single-breath analysis of $ETCO_2$. We recently showed, in a rabbit model, that sampling of $ETCO_2$ within the proximal endotracheal tube provided a good estimation of $PaCO_2$ without discontinuing fresh gas flow.[8] Continuous sampling of $ETCO_2$ within the proximal endotracheal tube in infants during ventilation with a circle system without discontinuing fresh gas flow has not been evaluated. In this study, we assessed the accuracy of continuous $ETCO_2$ sampling via needle aspiration from the proximal end of the endotracheal tube compared with the $ETCO_2$ obtained from the standard proximal connector in infants less than one year old.

Methods

This study was approved by the University of Virginia Human Investigations Committee. Fourteen infants, ASA physical status II or III, were scheduled for major neurological, reconstructive or cardiothoracic surgery. Following induction of anaesthesia, the tracheas were

TABLE

Age	Weight (kg)	$PaCO_2$ (mmHg)	$ETCO_2$(ProxETT) (mmHg)	$ETCO_2$(ProxConnector) (mmHg)
3 mth	5.2	41	36	36
4 mth	5.4	23	28	25
1 d	3.0	37	28	27
5 mth	5.6	38	39	31
5 mth	5.7	41	33	26
4 mth	7.3	37	38	34
3 mth	4.2	33	32	39
8 mth	6.1	34	37	34
9 mth	6.4	28	33	31
13 d	3.7	36	35	32
5 mth	5.9	34	35	29
12 mth	8.3	40	41	36
2 d	3.0	35	34	32
6 mth	7.2	37	37	31
Mean ± SD				
4.6 ± 3.4 mth	5.5 ± 1.6	35.3 ± 4.9	34.7 ± 3.8	31.6 ± 4.0

intubated with an endotracheal tube sized (3.0 to 4.0 mm ID) to maintain a leak at a pressure of 15–25 cm H_2O. Mechanical ventilation was maintained with a North American Drager ventilator and a paediatric circle system. Fresh gas flows were maintained between 2 and 3 $L \cdot min^{-1}$. Tidal volume was adjusted to approximately 10 $ml \cdot kg^{-1}$ with a respiratory rate of 15–20 breaths $\cdot min^{-1}$. An arterial catheter was inserted in the radial, dorsal pedis, or femoral artery for blood gas sampling.

A 22-gauge needle was inserted through the wall of the endotracheal tube as it exited the mouth of the infant. Side stream aspiration of expired gas was sampled at 150 $ml \cdot min^{-1}$ from the 22-gauge needle and at the standard proximal connector. The $ETCO_2$ was analyzed by raman spectroscopy (Albion Incorporated).[9] A blood gas sample was obtained from the arterial catheter 15 min after initiation of $ETCO_2$ sampling. The $PaCO_2$ was compared with the $ETCO_2$ sampled from within the endotracheal tube and at the proximal connector by one-way analysis of variance with repeated measures, followed by Newman-Keuls multiple comparison test.

Results

The patients' ages ranged from one day to 12 months (Table). The mean ± SD for age and weight were 4.6 ± 3.4 mth and 5.5 ± 1.6 kg. Oesophageal temperature and arterial blood pressure remained within normal limits. There were no problems or technical difficulties arising from the insertion of the needle into the endotracheal tube.

The $PaCO_2$ (35.3 ± 4.9 mmHg) was not significantly different from the $ETCO_2$ sample from within the proximal endotracheal tube (34.7 ± 3.8 mmHg). In contrast, the $PaCO_2$ was significantly higher ($P < 0.05$) than the $ETCO_2$ sampled at the proximal connector (31.6 ± 4.0 mmHg).

Discussion

In this study we demonstrated a simple technique which can be used to estimate continuously and accurately $PaCO_2$ in infants during ventilation with a circle system. Previously, discrepancies between $PaCO_2$ and $ETCO_2$ have been reported by numerous investigators.[1–6] Sampling $ETCO_2$ from the connector proximal to the endotracheal tube underestimates $PaCO_2$ because expired gas is diluted by fresh gas flow. This is particularly true in infants during ventilation with partial rebreathing systems, which directs high fresh gas flows towards the sample port.[10] When using a circle system, the difference between $PaCO_2$ and $ETCO_2$ may be less because the required fresh gas flow is lower and is not directed toward the sample port. Nevertheless, in this study there was a significant difference between $PaCO_2$ and $ETCO_2$ sampled at the proximal connector.

Gravenstein noted in a mock respiratory system that sampling more distally within the endotracheal tube improved the accuracy of $ETCO_2$ sampling, because of decreased dilution.[10] Badgwell demonstrated the accuracy of distal endotracheal sampling in infants and children.[5,6] Distal sampling requires insertion of a catheter to the distal tip of the endotracheal tube, which may be technically difficult and potentially obstructive. Bissonette devised a simpler method which used a needle inserted through the wall of the endotracheal tube while fresh gas flow was discontinued for single breath analysis of $ETCO_2$ in children.[7]

In this study we used a 22-gauge needle inserted

through the wall of the proximal endotracheal tube to sample $ETCO_2$ continuously in infants during ventilation with a circle system. In contrast to Bissonette, we did not discontinue fresh gas flow. We previously demonstrated in a rabbit model that $ETCO_2$ sampling within the endotracheal tube is not affected by high fresh gas flows or small tidal volumes when using a Mapleson circuit.[8] This study verifies the accuracy of sampling $ETCO_2$ within the proximal endotracheal tube without discontinuing fresh gas flow.

In seven of the 14 infants the $PaCO_2$ was lower than the $ETCO_2$ as measured in the proximal endotracheal tube. A negative $PaCO_2$ to $ETCO_2$ gradient has been reported by several investigators in adults,[1,11] but not in infants. Although very complex, this may partially be explained by infants' increased CO_2 production, which has been demonstrated to increase $ETCO_2$ to levels approaching venous CO_2.[12]

Dilution of expired CO_2 within the small infant endotracheal tube appears to be minimal as the $ETCO_2$ within the proximal endotracheal tube is not different from the $PaCO_2$. However, once the expired gas enters the larger proximal connector, dilution occurs, and $ETCO_2$ is significantly lower than $PaCO_2$. This is true despite a leak of 15 to 25 cmH_2O around the endotracheal tube. Furthermore, sampling within the proximal endotracheal tube does not seem to be affected by continuous sidestream sampling at a rate of 150 $ml \cdot min^{-1}$, despite reports that this may increase expired gas dilution.[13]

In summary, this study demonstrates that continous $ETCO_2$ sampling via a 22-gauge needle within the proximal endotracheal tube accurately estimates $PaCO_2$ in infants during ventilation with a circle system. This technique is simpler than distal sampling, more accurate than proximal connector sampling, and does not require discontinuation of fresh gas flow.

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