End-tidal carbon dioxide measurement in infants and children during and after general anaesthesia

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We have examined the reliability of end-tidal carbon dioxide ($PETCO_2$) monitoring as an estimate of arterial carbon dioxide tension ($PaCO_2$) in spontaneously breathing infants and children. Forty patients were studied in the post-anaesthetic care unit; 20 < 12 kg and 20 ≥ 12 kg. The $PETCO_2$ was sampled via a 5 cm 16 gauge catheter taped below an external naris and this measurement was compared with the $PaCO_2$ of a sample drawn from an indwelling arterial line. Twenty additional patients were studied during inhalational anaesthesia. The $PETCO_2$ was measured both from the proximal end of the elbow connector and from a 5 cm cannula inserted through the elbow. An arterial blood gas sample was obtained simultaneously. The arterial to end-tidal (Pa-ET) differences were compared between the two sites. Patients studied in the post-anaesthetic care unit showed good correlation between $PETCO_2$ and $PaCO_2$ regardless of weight: Pa-$ETCO_2$ of -0.6 ± 3.6 (<12 kg) and -1.1 ± 2.8 mmHg (≥12 kg). Patients studied during mask anaesthesia showed better correlation between $PETCO_2$ and $PaCO_2$ when $PETCO_2$ was sampled from thte cannula: Pa-$ETCO_2$ of 3.5 ± 4.8 mmHg (cannula), 8.6 ± 4.5 (elbow) ($P < 0.05$). These results suggest that end-tidal CO_2 monitoring is a useful and reliable method for assessing adequacy of ventilation in spontaneously breathing children weighing between 5.2 and 35 kg.

Cette étude vise à évaluer, en ventilation spontanée, la fiabilité du monitorage du CO_2 téléexpiratoire ($PETCO_2$) comme mesure de la tension du gaz carbonique artériel ($PaCO_2$) chez des nourrissons et des enfants. Une étude est réalisée d'abord à l'unité des soins postopératoires chez 40 patients: 20 < 12 kg et 20 ≥ 12 kg. L'échantillonnage de la $PETCO_2$ se fait par un cathéter 16G de 5 cm fixé sous une narine et la comparaison est établie avec un prélèvement artériel. Vingt patients additionnels sont étudiés pendant une anesthésie inhalatoire. La $PETCO_2$ est mesurée à la fois à l'extrémité proximale du raccord coudé et par une canule de 5 cm insérée a travers le raccord. (Un échantillon de sang artériel est prélevé simultanément. La différence artério-téléexpiratoire (Pa-ET) est comparée au niveau des deux sites. A l'unité des soins postopératoires, la corrélation entre $PETCO_2$ et $PaCO_2$ est bonne et indépendante du poids: Pa-$ETCO_2$ = $-0,6 \pm 3,6$ (<12 kg) et $-1,1 \pm 2,8$ mmHg (≥ 12 kg). Pendant l'anesthésie au masque, la corrélation a été meilleure entre $PETCO_2$ et $PaCO_2$ quand la $PETCO_2$ est prélevée par la canule: Pa-$ETCO_2$ de $3,5 \pm 4,8$ mmHg (canule), $8,6 \pm 4,5$ (raccord) ($P < 0,05$). Ces résultats suggèrent que le monitorage du CO_2 téléexpiratoire est utile et liable pour évaluer la suffisance de la ventilation chez des enfants pesant de 5,2 à 35 kg.

Key words
ANAESTHESIA: paediatric;
MONITORING: carbon dioxide.

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End-tidal carbon dioxide ($PETCO_2$) measurement is an important monitor for identification of intraoperative ventilatory problems in children undergoing general anaesthesia with tracheal intubation and intermittent positive-pressure ventilation.[1] End-tidal CO_2 monitoring through a tracheal tube has been studied extensively in infants and children.[2,3] Monitoring of ventilation is frequently necessary in both the intra- and postoperative periods regardless of the need for tracheal intubation. The value of $PETCO_2$ monitoring in children in whom the tracheas are not intubated has neither been established in the recovery room nor during mask anaesthesia.

Sampling end-tidal gas via a cannula inserted through nasal prongs or through a nasopharyngeal catheter has been shown to be a reliable way of monitoring $PETCO_2$ in spontaneously breathing adults.[4,5] End-tidal monitoring via a nasal sampling catheter has also been used in children sedated for dental procedures, but without reference to arterial CO_2 tensions.[6]

The purpose of this study was to determine the accuracy of $P_{ET}CO_2$ measurements in the estimation of $PaCO_2$ in spontaneously breathing infants and children in the recovery room and during mask anaesthesia.

Methods

Group I

With approval from the Human Studies Review Committee, 40 infants and children weighing less than 35 kg, who required indwelling arterial cannulae for intraoperative indications, were studied in the recovery room. Patients were stratified into two groups: Group Ia < 12 kg and Group Ib ≥ 12 kg. Patients with nasal obstruction, respiratory disease or right to left cardiac shunts were excluded.

On admission to the recovery room, all patients received supplementary oxygen by face mask or hood. A 5 cm 16 gauge intravenous cannula (Angiocath, Becton Dickinson Vascular Access, Mississauga, Ont) was taped just below an external naris and connected to the sampling tube of the capnometer. The $P_{ET}CO_2$ and oxygen saturation (SaO_2) were recorded throughout the study using a capnometer/oximeter with an aspiration rate of 200 $ml \cdot min^{-1}$ (Model 255) and two channel chart recorder (Model DR 103) (Datex Instrumentarium Corporation, Helsinki, Finland) which were calibrated prior to each use.

The O_2 flow was gradually reduced to optimize the waveform or until a minimum flow of 2 $L \cdot min^{-1}$ was reached. With the patient lying quietly, the $P_{ET}CO_2$ was recorded during a 20-sec interval and an arterial blood gas sample was obtained simultaneously. The blood gas sample was immediately analyzed in a NOVA Stat Profile 5 Analyzer (NOVA, Biomedical, Waltham, Massachussetts). The $P_{ET}CO_2$, $PaCO_2$, respiratory rate, O_2 flow and SaO_2 were recorded and the arterial to end-tidal CO_2 gradient ($Pa\text{-}_{ET}CO_2$) was calculated.

Group II

With approval from the Human Studies Review Committee and informed parental consent, 20 unpremedicated ASA I or II children <12 yr of age and <35 kg in weight undergoing cystoscopy or circumcision were studied. Patients with respiratory disease and right to left cardiac shunts were excluded.

Anaesthesia was induced and maintained with halothane and nitrous oxide in oxygen using a T-piece breathing system with a gas-sampling port in the elbow connector. End-tidal gas was sampled from two sites: (i) from the sampling port of the elbow and (ii) from a 5 cm 16 gauge intravenous cannula inserted through the sampling port. Fresh gas flow (FGF) was adjusted to prevent rebreathing as indicated by a failure of the capnogram trace to return to baseline. After the patient was positioned for the procedure, but before surgical stimulation, an arterial blood sample was obtained and the $PaCO_2$ was measured as in Group I. Concurrently, $P_{ET}CO_2$ was recorded from the cannula and then directly from the sampling port in the elbow with the cannula removed. End-tidal CO_2 readings were recorded for ten seconds at each of the sample sites. When a plateau was not obtained, the peak value of the $P_{ET}CO_2$ was recorded.[3] Respiratory rate, FGF and SaO_2 were also recorded. The arterial to end-tidal differences were subsequently calculated.

Statistics

Parametric data are reported as mean ± SD. In the postoperative groups, demographic and parametric variables were compared using the unpaired t test. In the intraoperative group, the arterial to end-tidal CO_2 differences obtained at the elbow connector and at the tip of the 5 cm cannula were compared using paired t tests. Statistical significance was accepted as $P < 0.05$.

TABLE I Demographic data and measurements in postoperative patients

	Group Ia (<12 kg)	*Group Ib (≥12 kg)*	
Number of patients	20	20	
Age (mo)	15.0 ± 9.5	76.0 ± 23.5	$P < 0.05$
Weight (kg)	9.3 ± 2.0	22.0 ± 6.1	$P < 0.05$
Respiratory rate (breaths · min^{-1})	33.0 ± 11.0	24.0 ± 6.0	$P < 0.05$
Fresh gas flow ($L \cdot min^{-1}$)	4.4 ± 1.4	5.8 ± 0.8	$P < 0.05$
SaO_2	100.0 ± 1.0	99.0 ± 1.0	$P < 0.05$

Results

Group Ia differed from Group Ib with respect to age, weight, respiratory rate and fresh gas flow ($P < 0.05$) (Table I). Fresh gas flow was reduced below 4 $L \cdot min^{-1}$ in only one of the 40 patients. In Group Ia the patients ranged in weight from 5.2 to 11.7 kg and in Group Ib, from 12.8 to 34.7 kg. However, mean $PaCO_2$, $P_{ET}CO_2$ and arterial to end-tidal differences were clinically similar (Table II). There were ten patients with negative arterial to end-tidal gradients in Group Ia (<12 kg) and twelve in Group Ib.

The patients in Group II ranged in age from five months to 9.25 yr and in weight from 7.2 -29.0 kg (Table III). Arterial CO_2 tension ranged from 42.0–54.7 mmHg

TABLE II Arterial end-tidal and a-ET CO_2 differences in postoperative patients

	Group Ia	Group Ib	
$PaCO_2$ (mmHg)	38.6 ± 5.0	39.0 ± 5.6	NS
$PETCO_2$ (mmHg)	39.3 ± 4.5	40.1 ± 4.7	NS
Pa-$ETCO_2$ (mmHg)	−0.65 ± 3.6	−1.15 ± 2.8	NS

TABLE III Demographic data and measurements during mask anaesthesia

Number	20
Age	45.6 ± 38.6 mo
Weight	15.8 ± 7.21 kg
Fresh gas flow	6.4 ± 1.3 L · min^{-1}
Respiratory rate	48.0 ± 10 breaths · min^{-1}
Pa-$ETCO_2$ (elbow)	8.6 ± 4.5 mmHg
Pa-$ETCO_2$ (cannula)	3.5 ± 4.8 mmHg*

*$P < 0.001$ compared to Pa-ET (elbow).

and was more closely approximated by end-tidal measurements through the cannula than at the elbow connector site ($P < 0.05$) (Table III). Negative gradients occurred in two patients.

There were no complications associated with either phase of the study.

Discussion

This study shows that end-tidal CO_2 sampling can provide a continuous estimate of $PaCO_2$ in spontaneously breathing infants and children both during mask anaesthesia and in the post-anaesthetic care unit.

In postoperative patients, sampling at the external naris provided a good estimate of $PaCO_2$ regardless of weight. The use of end-tidal CO_2 measurement to estimate $PaCO_2$ in infants has been fraught with difficulties because of small tidal volumes, high respiratory rates and relatively high fresh gas flows during anaesthesia. Badgwell *et al.* showed that, in patients <12 kg with a tracheal tube in place and ventilated with intermittent positive pressure, Pa-$ETCO_2$ was greater than in larger children unless sampling was done in the distal airway.[2] This study, however, demonstrates that the value of $PETCO_2$ as an estimate of $PaCO_2$ in the spontaneously breathing, infant ≤12 kg is not different from measurement in the larger child.

The addition of the cannula to the end-tidal sampling line provided a better estimate of $PETCO_2$ in infants and children undergoing mask anaesthesia than did measurement obtained at the top of the elbow sampling port. The improvement in accuracy of end-tidal measurement is somewhat surprising since the sampling site was not extended into the distal airway as in previous studies of intubated patients.[2,3] Recent work by Halpern *et al.* has demonstrated that considerable dilution by fresh gas does not extend beyond the connector of the endotracheal tube and it therefore may not be necessary to sample at the distal end of the tube.[7] Similarly, in the patient breathing spontaneously during mask anaesthesia, it appears that the addition of a 5 cm cannula at the sampling port of the elbow to extend the sampling site to the mask is sufficient to produce a significant improvement in end-tidal CO_2 measurement.

The number of negative a-ET differences, particularly in the postoperative group, is of interest. Rich, in a study of neonates in whom the tracheas were intubated and lungs ventilated, found a negative gradient in 7 of 14 infants.[8] In this situation, negative gradients are likely related to larger than normal tidal volumes which allow gas from "slow alveoli" to reach the mouth and result in better ventilation of dependent alveoli.[9] Although large tidal volumes may be a factor in the awake, crying infant, this would not be expected to play a large role in our postoperative patients since recordings were made during quiet breathing. Negative gradients have also been observed in spontaneously breathing adults.[10] McNulty *et al.* in their study found that the largest negative gradients were associated with sudden increases in $PaCO_2$.[10] Since a single measurement of $PaCO_2$ was made in the present study, we are unable to confirm the occurrence of this phenomenon in children, but it may have played a role. Overestimation of $PETCO_2$ may also be the result of interference of water vapour in the measurement of CO_2 by an infra-red analyzer. Although Severinghaus has described a method of correcting measurements to BTPS (body temperature and pressure, saturated)[11] it is difficult to make an appropriate correction for water vapour at body temperature in the present investigation as the sampling site is not within the airway. Déry has shown that both temperature and relative humidity change considerably from carina to mouth.[12]

This study demonstrates that end-tidal monitoring in healthy infants and children breathing spontaneously during mask anaesthesia or in the postanaesthetic care unit is useful over the usual clinical range of $PaCO_2$. It also suggests that this method of end-tidal gas sampling may prove helpful during conscious sedation, neuroleptanalgesia and regional anaesthesia techniques.

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