Single breath end-tidal CO_2 estimates of arterial PCO_2 in infants and children

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To determine whether single breath end-tidal carbon dioxide ($P_E'CO_2$) measurements accurately estimate arterial PCO_2 ($PaCO_2$) in infants and children, 68 healthy infants and children, ASA physical status I or II scheduled for peripheral and lower abdominal surgery requiring endotracheal intubation were studied. A 3 ml single breath sample was obtained with a 23-gauge needle which was inserted through the wall of the endotracheal tube below the connector. The mean ± SD $P_E'CO_2$ 33.6 ± 6.9 mmHg did not differ significantly from the corresponding mean ± SD $PaCO_2$ 33.6 ± 5.6 mmHg. The coefficient of determination, r^2, was 0.97. The authors conclude that single breath $P_E'CO_2$ measurements from the proximal end of the endotracheal tube accurately estimate the $PaCO_2$ in infants and children.

Two non-invasive techniques to estimate end-tidal CO_2 ($P_E'CO_2$) in infants and children have been described: the single breath technique[1] and the continuous gas sampling technique.[2] Fletcher recommended the use of a single breath end-tidal gas sample to estimate the arterial PCO_2, $PaCO_2$) accurately. However, his protocol required complex equipment which is not generally available to the practising anaesthetist.[1,3,4] In contrast, Brandom *et al.* recommended mass spectrometry with continuous gas sampling from the proximal end of the endotracheal tube to measure continuous end-tidal anaesthetic concentrations accurately in infants and children.[2] Using a mass spectrometer with the continuous sampling technique, Kaplan and Paulus demonstrated that fresh gas flows continuously through the Mapleson F circuit (i.e., Jackson-Rees' modification of Ayre's t piece) during both inspiration and expiration.[5] They suggested that the fresh gas flow could contaminate the exhaled gases and lead to inaccurate estimates of end-tidal gas concentrations.

The problems associated with accurate end-tidal gas sampling are magnified in small infants and children. Because alveolar ventilation is a smaller fraction of the fresh gas flow in these patients than in adults, discrepancies between the true end-tidal gas concentration and the sampled end-tidal gas concentration may be clinically significant. If end-tidal gas sampling is to become a useful tool in paediatrics, then a technique which provides a good correlation between end-tidal and arterial gas concentrations in all age groups must be developed.

Badgwell *et al.* investigated the accuracy of non-invasive estimates of $PaCO_2$.[6] Although they established guidelines for accurate estimation of $P_E'CO_2$ their guidelines apply only to continuous end-tidal CO_2 analyzers and not to single breath samples. In order to determine whether accurate non-invasive estimates of $PaCO_2$ are possible without automated $P_E'CO_2$ analyzers, we investigated the use of the single breath $P_E'CO_2$ technique as a non-invasive accurate estimate of $PaCO_2$ in infants and children.

Key words

ANAESTHESIA: paediatric; CARBON DIOXIDE: tension, alveolar, arterial, end-tidal; MEASUREMENT, TECHNIQUES: capnography; VENTILATION: carbon dioxide tension, mechanical.

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Methods

With approval from the Human Review Committee, 68 healthy infants and children, ASA physical status I or II, scheduled for peripheral and lower abdominal surgery requiring tracheal intubation were studied. All patients were positioned supine and horizontal during the study and monitored with a blood pressure cuff, electrocardiogram, radial arterial Doppler probe, precordial stethoscope and a temperature probe. Anaesthesia was induced with thiopentone 5 $mg \cdot kg^{-1}$, atropine 0.02 $mg \cdot kg^{-1}$ and

succinylcholine 1.5 mg · kg^{-1}. Following tracheal intubation, anaesthesia was maintained with a volatile anaesthetic agent in 50 per cent nitrous oxide and 50 per cent oxygen. The chest was auscultated to verify the tracheal position of the tracheal tube. The lungs were mechanically ventilated with an Air-Shields ventimeter through a Jackson-Rees' modification of the Ayre's t piece.

The fresh gas flows were determined according to published guidelines: 1000 ml + 100 ml · kg^{-1} for infants and children less than 30 kg body weight and 2000 ml + 50 ml · kg^{-1} for children greater than 30 kg in body weight.[7] The respiratory rate was between 35 and 45 breaths · min^{-1} for prematures and newborns, 30–35 breaths · min^{-1} for infants less than six months of age, and 15–30 breaths · min^{-1} for older infants and children. Rectal temperature was recorded throughout the study and normothermia was maintained.

After 15 minutes of controlled ventilation, a 23-gauge needle was inserted through the wall of the endotracheal tube immediately below the connector with the bevel directed toward the distal end. During the next breath, at peak inspiration, the fresh gas line was disconnected temporarily from the anaesthetic machine so that 3 ml of expiratory gas could be aspirated through the needle into a 3 ml plastic syringe at end–expiration. An arterial blood sample was obtained simultaneously from either an indwelling arterial cannula or a percutaneous arterial puncture. Both end–tidal and arterial blood samples were analyzed in a Corning 175 blood:gas analyzer uncorrected for body temperature.[8] After the end–tidal sample was analyzed, the sample chamber in the Corning analyzer was flushed twice.

Statistical significance, $P < 0.05$, was accepted. The $PE'CO_2$ and $PaCO_2$ measurements were compared using the paired t test. Linear regression analysis and the coefficient of determination, r^2, were used to describe the relationship between the $PE'CO_2$ and $PaCO_2$.

Results

The mean ± SD age and weight for the patients were 6.4 ± 5.1 yr and 18.4 ± 16.3 kg. Age was from three weeks to 14 years.

The mean ± SD $PE'CO_2$, 33.6 ± 6.9 mmHg, did not differ significantly from the $PaCO_2$, 33.6 ± 5.6 mmHg. The relationship between $PE'CO_2$ and $PaCO_2$ is shown in the Figure. The coefficient of determination, r^2, was 0.97. We did not observe any variation in the calculated $PaCO_2$-$PE'CO_2$ differences at the extremities of age, i.e., young adolescents and small infants.

Rectal temperature remained within normal limits (35.7° C to 37.5° C). There were no complications as a result of the study.

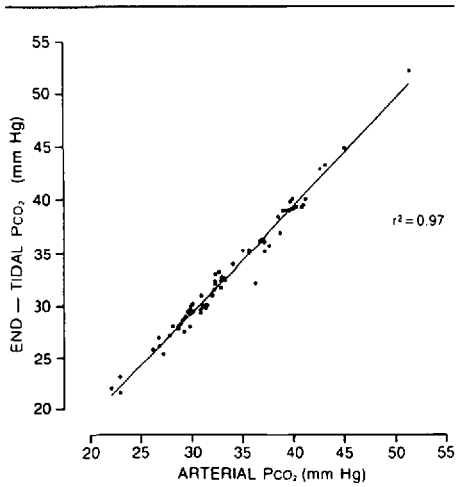

FIGURE Relationship between single breath end–tidal CO_2 and arterial PCO_2 measurements in infants and children ($r^2 = 0.97$).

Discussion

This study was undertaken to determine whether single breath $PE'CO_2$ measurements accurately estimate the $PaCO_2$ in infants and children during anaesthesia when arterial cannulation is not indicated and continuous $PE'CO_2$ monitoring devices are not available.

Several investigators have studied the relationship between $PE'CO_2$ and $PaCO_2$ in adults.[9,10] They found that in several patients, $PE'CO_2$ underestimated $PaCO_2$ by 8.0 mmHg or greater. This discrepancy suggested that $PE'CO_2$ monitoring may not be reliable in adults.[9,10] In paediatric patients, Badgwell *et al.* demonstrated that with continuous end–tidal gas analyzers, $PE'CO_2$ measurements obtained from the proximal end of the endotracheal tube did not accurately predict $PaCO_2$ measurements in infants and children weighing less than 8 kg who were ventilated mechanically through a coaxial circuit with a continuous flow, time-cycled ventilator.[6] They also demonstrated that the difference between $PaCO_2$ and $PE'CO_2$ measurements in these patients could be minimized if the $PE'CO_2$ was obtained from the distal and not the proximal end of the endotracheal tube.[6] In contrast, the results of this study indicate that proximal measurements of $PE'CO_2$ do indeed accurately estimate $PaCO_2$ provided the fresh gas flow is interrupted during the period of measurement.

In summary, we have shown that the non-invasive single breath $PE'CO_2$ measurements accurately estimate

the $PaCO_2$ in infants and children under anaesthesia and recommend this manoeuvre as a useful adjunct to clinical care when arterial cannulation is not indicated and continuous $P_E'CO_2$ monitoring devices are not available.

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Résumé

L'étude du CO_2 en fin d'expiration ($P_E'CO_2$) par la technique d'échantillonage unique chez les jeunes enfants a été développée dans le but d'estimer la tension artérielle du CO_2. Soixante-huit jeunes enfants avec un état physique I ou II de la classification ASA ayant été cedulés pour chirurgie abdominale basse ou périphériques sous anesthésie générale avec intubation endotrachéale ont été étudiés. La procédure d'échantillonage respiratoire simple était obtenue a l'aide d'une ajuille #23 insérée sous le connecteur dans le tube endotracheal en fin d'expiration. Le et $P_E'CO_2$ ± DS 33.6 ± 6.9 mmHg n'était pas significativement différent de la moyenne ± DS 33.6 ± 5.6 mmHg observée pour $PaCO_2$. Le coefficient de détermination, r^2, était 0.97. Les auteurs conclurent que la technique de mesure du $P_E'CO_2$ par échantillonage simple peut adéquatement estimer la $PaCO_2$ chez les jeunes enfants même eu l'absence d'un moniteur et $P_E'CO_2$ à debit continue.