CORRELATION OF ALVEOLAR \( P_{\text{CO}_2} \) ESTIMATED BY INFRA-RED ANALYSIS AND ARTERIAL \( P_{\text{CO}_2} \) IN THE HUMAN NEONATE AND THE RABBIT

J. M. EVANS, M. I. J. HOGG AND M. ROSEN

SUMMARY

The performance of an infra-red analyser (Beckman LB-2) in sampling alveolar gas at ventilatory frequencies and volumes occurring in the human neonate has been examined. The optimum sampling flow rate was found to be 300 ml/min; at this flow the 90% response time of the analyser-catheter system was 140 ms. Correlation of estimated alveolar \( P_{\text{CO}_2} \) and arterial \( P_{\text{CO}_2} \) was performed in the rabbit which has a ventilatory rate and tidal volume similar to those of the human neonate. There was a good correlation between maximum end-expired \( P_{\text{CO}_2} \) and arterial \( P_{\text{CO}_2} \) over a wide range of ventilatory rates (10–100 b.p.m.); maximum \( P_{\text{eCO}_2} \) was a better index than mean \( P_{\text{eCO}_2} \) or alveolar plateau \( P_{\text{eCO}_2} \).

Continuous infra-red analysis of end-expired carbon dioxide concentration provides a good estimate of alveolar or arterial \( P_{\text{CO}_2} \) in the fit adult (Cotes, 1975) The validity of the method is uncertain in the fit neonate because the expiratory flow rate is small and the duration of expiration short. The performance of an infra-red gas analyser in sampling alveolar gas at the ventilatory frequency and tidal volume of the neonate has been examined.

METHOD

Optimal sample flow rate for alveolar sampling

A Beckman LB-2 infra-red analyser having nominal 90% response time of 100 ms was used. In 10 neonates end-expired carbon dioxide concentration was recorded graphically (Devices M19) for 1 min at sampling flows of 100, 200, 300, 400 and 500 ml/min (Evans, Hogg and Rosen, 1977). The mean percentage of breaths which produced an alveolar plateau was measured. It was assumed that alveolar plateaux would be recorded with increasing frequency as conditions for alveolar gas sampling improved. An alveolar plateau was defined arbitrarily as present when the expired carbon dioxide concentration was within 0.2% of the peak concentration for at least 200 ms before the peak.

Correlation of estimated alveolar \( P_{\text{CO}_2} \) and arterial \( P_{\text{CO}_2} \)

It was considered unethical to submit fit neonates to arterial or arterialized capillary blood sampling. Therefore a study of the correlation of the estimated alveolar \( P_{\text{CO}_2} \) and arterial \( P_{\text{CO}_2} \) was made in animals. The rabbit was chosen, since it has ventilatory volumes and rates similar to those of the human neonate (Alltman and Dittmer, 1971).

Preparation of rabbits. Rabbits were anaesthetized with increments of ketamine hydrochloride i.v. The mouth was sealed with adhesive tape to ensure nasal ventilation. A femoral artery was cannulated and body temperature was measured with a rectal thermister probe.

Measurements of end-expired carbon dioxide concentration. A soft plastic catheter, lightly smeared with 1% lignocaine jelly, was inserted into a nostril. Gas was sampled and analysed by the infra-red analyser at a flow of 300 ml/min. The analyser was calibrated frequently with carbon dioxide-air mixtures prepared with a Wosthoff pump (Model 15A27/3F). The output signal of the analyser was recorded on magnetic tape (Bell and Howell 3200) and later recorded on a graph (Devices M19).

Procedure. Measurements were made at ventilatory rates between 10 and 100 per minute. End-expired carbon dioxide concentration was recorded for 60 s and arterial blood (1 ml) was withdrawn over 10 s, in the middle of the recording, into heparinized plastic syringes and arterial \( P_{\text{CO}_2} \) was measured immediately (Radiometer PHM7). Corrections were made for differences between body and electrode temperature (Kelman and Nunn, 1966). Ventilatory depression was produced with increments of i.v. morphine; excessive depression was antagonized by naloxone. Measurements were made at least 5 min after medication when the end-expired carbon dioxide concentration had stabilized.
Interpretation of recordings. Each recording of end-expired carbon dioxide concentration was analysed to derive three measurements: (1) the mean end-expired carbon dioxide concentration; (2) the maximum end-expired carbon dioxide concentration; (3) the mean end-expired carbon dioxide concentration of expirations with an alveolar plateau (as defined above).

RESULTS

Optimum sample flow rate
At a sample flow rate of 300 ml/min almost 40% of expirations had a defined alveolar plateau (fig. 1). At lesser and greater flows the percentage was less. The 90% response time of the analyser and catheter system at 300 ml/min to an instantaneous gas change was 140 ms (SD 7).

Correlation of estimated alveolar \( \text{PCO}_2 \) and arterial \( \text{PCO}_2 \) in rabbits
Forty-one paired measurements were made in three rabbits. Their mean weight was 2.96 kg. Each received ketamine in increments of 5-10 kg/mg (mean total 134 mg/kg), morphine in increments of 5-7.5 mg (mean total 19 mg/kg) and naloxone (0.1 mg). Linear regressions of estimated alveolar \( \text{PCO}_2 \) and arterial \( \text{PCO}_2 \) were produced for each of the three derived estimates of alveolar \( \text{PCO}_2 \). The regression related to alveolar plateaux was based on 24 points since 17 recordings contained no alveolar plateau. In all three regressions the intercept (positive, on the y axis) was not significantly different from zero (\( P > 0.1 \)) in all cases. Values of the slope, the standard error of the slope and the significance of the difference between the slope and unity with the lines constrained through zero are given in table I. The best correlation was provided by the maximum end-expired carbon dioxide concentration; this regression with individual points and 95% confidence limits of individual observations is shown in figure 2. The arterial-alveolar \( \text{PCO}_2 \)

<table>
<thead>
<tr>
<th>Table I. Statistical details of linear regressions, constrained through zero, of alveolar ( \text{PCO}_2 ) estimated from three derivatives of end-expired recordings and arterial ( \text{PCO}_2 ) in the rabbit</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of measurements</td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td>Maximum end-expired</td>
</tr>
<tr>
<td>Mean end-expired</td>
</tr>
<tr>
<td>Mean end-expired of plateau</td>
</tr>
</tbody>
</table>

Fig. 1. Mean (SEM) percentage of expirations of 10 healthy neonates providing defined alveolar plateaux at various analyzer sample flow rates.

Fig. 2. Regression line, constrained through zero, and 95% confidence limits of a single observation showing correlation of alveolar \( \text{PCO}_2 \), estimated from maximum end-expired \( \text{PCO}_2 \) in 1 min, and arterial \( \text{PCO}_2 \).
CORRELATION OF $P_{ACO_2}$ AND $P_{ACO_2}$

Fig. 3. Arterial-alveolar $PCO_2$ gradient plotted against ventilatory rate (10–100 b.p.m.). Individual observations, the unconstrained regression line, 95% confidence limits of the slope and individual observations are shown.

DISCUSSION

The animal study indicates that measurements of maximum end-expired carbon dioxide concentration by continuous infra-red analysis can provide a good estimate of arterial $PCO_2$ at ventilatory rates and tidal volumes comparable with those of the human neonate. The continuous collection of expired gas through a nasal catheter is less complicated than methods of end-expired collection which require an airtight seal between apparatus and neonate (Nelson et al., 1962). For measuring carbon dioxide the infra-red analyser is simpler, cheaper and more convenient than is a mass-spectrometer.

It was surprising to find that the alveolar plateau was not the best guide to $PA_{CO_2}$. Ventilation in the neonate is often irregular in frequency and volume and it follows that there will be a corresponding breath-by-breath change in alveolar ventilation and alveolar $PCO_2$. The analyser is most likely to record an alveolar plateau when expired flow is high and prolonged, that is, when there is a large expired tidal volume. An alveolar plateau is therefore most likely to be recorded when the alveolar $PCO_2$ has been lowered by a large tidal volume. This would explain the observation that, when ventilatory frequency is irregular, the end-expired carbon dioxide concentration recorded in those breaths producing a clear plateau may be lower than adjacent breaths which fail to provide a plateau (fig. 4). The use of the maximum end-expired carbon dioxide concentra-
tration as a guide to alveolar $P_{CO_2}$ has a practical advantage, since it can be obtained easily by monitoring electronically the output signal of the analyser with a “peak-hold” circuit.

REFERENCES


