Transcutaneous Carbon Dioxide for Short-Term Monitoring of Neonates

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We studied transcutaneous $p_{\text{CO}_2}$ monitoring in 70 neonates, most of them premature with respiratory distress syndrome. Measurements were at 44 °C. Calibration drift was large in some instances. Least squares linear regression analyses of transcutaneous $p_{\text{CO}_2}$ ($y$) vs arterial $p_{\text{CO}_2}$ ($x$) in kilopascals showed, for all observations ($n = 516$), for one observation randomly selected from each patient ($n = 70$), and for the first observation from each patient ($n = 70$): $y = -0.28 + 1.80x$, $y = 0.01 + 1.74x$, and $y = 0.73 + 1.63x$, respectively. Regression lines for individual patients with 14 or more observations each were not coincident ($F = 2.80, p < 0.002$). Transcutaneous $p_{\text{CO}_2}$ monitoring was most useful clinically as a means of following short-term trends in arterial $p_{\text{CO}_2}$ continuously during extubation and afterward when avoiding re-intubation. In view of the potential for error associated with drift, we recommend that intervals between calibrations be limited to about 3 h.

Additional Keyphrases: blood gases · arterial CO2 tension

We studied noninvasive monitoring of transcutaneous (tc) carbon dioxide tension ($p_{\text{CO}_2}$) over a period of 18 months in our Neonatal Intensive Care Unit. Bedside measurement of tc $p_{\text{CO}_2}$ offers a means of following trends in arterial $p_{\text{CO}_2}$ ($p_{\text{acO}_2}$) continuously without the need for repetitive sampling. Particularly in premature infants, invasive sampling is wasteful of blood and can lead to vascular and infection complications. Additionally, the trauma of the sampling procedures can alter blood gas values, rendering them unreliable for clinical management (1). We found that tc $p_{\text{CO}_2}$ data aided respiratory management, especially during intubation, weaning from a respirator, and extubation.

Methods and Materials

To measure tc $p_{\text{CO}_2}$, we used microprocessor-based TCM20 carbon dioxide monitors and matching electrodes (Radiometer America, Inc., Cleveland, OH 44145), with Radiometer S44716 electrode filling solution. For two-point calibration, we used the tonometer cell mounted on the TCM20 unit, in combination with a Radiometer A7405 calibration unit. Carbon dioxide contents of the calibrating gases were 50 mLL (about 38 Torr$^1$ or 5 kPa) and 100 mLL (about 76 Torr or 10 kPa). The temperature setting of the tc $p_{\text{CO}_2}$ electrode was 44 °C during both calibration and clinical monitoring. Electrode heat is used to produce vasodilation of the capillaries in the skin immediately opposite the electrode sensing area surface, thereby facilitating tc $p_{\text{CO}_2}$ responses to systemic changes in $p_{\text{acO}_2}$. We placed the tc $p_{\text{CO}_2}$ electrode on the chest or abdomen. For in vitro (37 °C) measurements of arterial blood gases from umbilical, radial, or dorsalis pedis sites, we used an IL813 blood-gas analyzer (Instrumentation Laboratory, Lexington, MA 02173), with accepted quality-control routines (2, 3) for small sample volumes (about 0.3 mL).

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$^1$ 1 Torr $= 133.3$ Pa

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The patients were in our Neonatal Intensive Care Unit. All neonates we monitored, 39 females and 31 males, had cardiopulmonary disease. The most frequent diagnosis was infant respiratory distress syndrome. Mean gestational age was 30 (SD 3) weeks, and mean birth weight was 1383 (SD 609) g.

All data were processed by statistical package programs on a large mainframe computer. We performed least-squares linear regression analyses of (a) all observations (n = 516) collated from 500 monitoring sessions, (b) the set of first observations from each patient (n = 70), (c) a set of single observations selected without conscious bias from each patient (n = 70), and (d) individual sets (n = 10) of observations for each patient who had 14 or more observations. An observation consisted of \( p_{ACO_2} \) and the coincident tc \( P_{CO_2} \) at the time of blood sampling. To demonstrate the validity of \( p_{ACO_2} \) observations at the bedside, we also calculated the ratio of \( P_{ACO_2} \) to tc \( P_{CO_2} \) with each successive observation for individual patients.

**Results**

After each monitoring session, we evaluated calibration drift. Greatest variability in drift was associated with prolonged monitoring intervals and measurement of high \( P_{CO_2} \) values. For the low \( P_{CO_2} \) calibration tension, drift averaged 0.2 (SD 3.1, range –10.0 to 19.0) Torr. For the high \( P_{CO_2} \) calibration tension, drift averaged 0.0 (SD 5.6, range –20.0 to 42.0) Torr. The average duration of the monitoring sessions was 3.0 (SD 0.5) h. Figure 1 shows all 516 observations at the least squares linear regression line. The standard error of estimate was 12.6 Torr (dashed lines in the figure). Table 1 summarizes the results of the regression analyses. Statistical testing (4) showed a significant difference (t = 3.272, p < 0.002) between intercepts, but not slopes, of the regression lines for the first observation and randomly selected sets. We reviewed the outliers having standardized residuals greater than 3.0, but found no technical errors in determinations of tc \( P_{CO_2} \) or \( P_{ACO_2} \). Figure 2 shows the least squares linear regression lines for individual patients. Statistical analysis (4) showed that the regression lines were not coincident (F = 2.80, p < 0.002).

**Discussion**

The greater \( P_{CO_2} \) at the electrode–skin interface as compared with \( P_{ACO_2} \) results from several factors, including the local heating of the blood under the electrode. The effects of increased temperature on blood \( P_{CO_2} \) have been described (5). However, because of the size of the difference in tc \( P_{CO_2} \) and \( P_{ACO_2} \), other factors may be involved, such as counter-current exchange in the capillary network near the surface of the skin, local trapping of carbon dioxide, increased skin metabolism as a result of electrode heat, incomplete "arterialization" of the local microvasculature, and heat-induced inhibition of carbonic anhydrase.

Calibration drift was large in some monitoring sessions. Additionally, because determination of drift is retrospective and may be nonlinearly related to time, it must be viewed as a potential source of error in monitoring sessions lasting 3 h or longer, especially in the higher ranges of \( P_{CO_2} \). Failing electrodes may be identified by their excessive drift, instability during the calibration procedure, or prolonged response time. The tendency for observations to lie above the regression line in the range of \( P_{ACO_2} \) equal to 60 to 90 Torr (Figure 1) may reflect the effect of heparinization of the blood-gas sample when less than 0.6 mL of blood is drawn (6). The reproducibility of the relationship of tc \( P_{CO_2} \) to \( P_{ACO_2} \) is exemplified by the least squares linear regression analyses, with the randomly selected set representing an attempt.
Fig. 2. Least squares linear regression lines of tc \( p_{\text{CO}_2} \) vs \( p_{\text{aCO}_2} \) for individual patients. Solid portions of the lines indicate the range of \( p_{\text{aCO}_2} \) for each patient. The table insert gives \( n \), the number of observations; \( a \), the intercept; \( b \), the slope; and \( r \), the correlation coefficient.

to exclude bias due to multiple samples from individual patients, and the first observation set representing an attempt to exclude any influence resulting from the development of chronic pulmonary disease during the hospitalization. We found no statistically significant difference in monitoring characteristics during the first 24 postnatal hours in our premature infants.

Our results indicate different regression relationships between tc \( p_{\text{CO}_2} \) and \( p_{\text{aCO}_2} \) in individual patients. Full characterization of the relationship in an individual patient may not be possible, because not many blood samples can be taken and the duration of hospitalization is limited. In view of this and the potential for drift, we believe that the principal value of tc \( p_{\text{CO}_2} \) measurement lies in following short-term trends in \( p_{\text{aCO}_2} \) continuously, without the need for repetitive blood sampling. We recommend a simple, practical approach to the bedside use of tc \( p_{\text{CO}_2} \) data. For a new patient, determine the initial value of the ratio of \( p_{\text{aCO}_2} \) to tc \( p_{\text{CO}_2} \) at the beginning of the monitoring session after obtaining a blood specimen and measuring \( p_{\text{aCO}_2} \). Up to the time of the next blood specimen—typically at the beginning of the next monitoring session—multiplication of this ratio by the value of tc \( p_{\text{CO}_2} \) yields an estimate of \( p_{\text{aCO}_2} \). As experience accumulates, one might use the mean ratio for the population of patients or for the individual patient under consideration. Besides being fast, this bedside approach, through a serial tabulation or plot of these ratios of \( p_{\text{CO}_2} \) values, provides a means of quickly identifying potential technical irregularities.

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References