Comparison of Transcutaneous and Alveolar Partial Pressure of Carbon Dioxide During Carbon Dioxide Breathing in Healthy Children*

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In 18 healthy children three to 13 years of age, the transcutaneous partial pressure of carbon dioxide (PtcCO₂) (Radiometer electrode) and the alveolar partial pressure of carbon dioxide (PaCO₂) (Beckman analyzer) were measured simultaneously during the breathing of room air and 5 percent carbon dioxide. The PtcCO₂ electrode was placed on the anterior thorax and heated to 42°C. The PaCO₂ was calculated on the 4/5 part of the carbon dioxide expired trace. Minute ventilation (Ve) was measured in 11 cases. There was a significant correlation between PtcCO₂ (in millimeters of mercury) and PaCO₂ (in millimeters of mercury) while breathing room air (PtcCO₂ = 0.82 PaCO₂ + 19.7; r = 0.55; p < 0.02) and while breathing 5 percent carbon dioxide (PtcCO₂ = 0.77 PaCO₂ + 22.5; r = 0.61; p < 0.01); however, the ratio of PtcCO₂ over PaCO₂ was significantly lower while breathing 5 percent carbon dioxide (p < 0.01) than while breathing room air. When considering the relationship between the increase in Ve (Δ Ve) while breathing 5 percent carbon dioxide and the changes in PaCO₂ (ΔPaCO₂) or in PtcCO₂ (ΔPtcCO₂), a significant correlation was found only between Δ Ve and ΔPaCO₂, i.e., Δ Ve = 0.41 Δ PaCO₂ + 0.44 (r = 0.63; p < 0.01). These results suggest that breathing carbon dioxide modified the factors acting on PtcCO₂, possibly by changes in the vasomotor tone of cutaneous blood vessels. These modifications appeared to be variable from subject to subject. Therefore, we conclude that PtcCO₂ does not appear to be an accurate quantitative index to assess ventilatory response to carbon dioxide.

The ventilatory response to carbon dioxide is usually assessed by the change in the alveolar partial pressure of carbon dioxide (PaCO₂). The sampling of alveolar gas requires a special apparatus in young children and infants with small tidal volumes and respiratory flows. It would be a distinct advantage to substitute the sampling of PaCO₂ by the continuous recording of the transcutaneous partial pressure of carbon dioxide (PtcCO₂), as has been suggested. The skin-surface carbon dioxide tension measured by a heated electrode is greater compared to the arterial partial pressure of carbon dioxide (PaCO₂). The larger value of PtcCO₂ is principally due to the anaerobic temperature coefficient of the blood for carbon dioxide, the local carbon dioxide production from increased metabolism, the arteriolarcellular carbon dioxide difference, and a counter-current exchange in the dermal capillary loops. Several conditions have been shown to modify the amount of difference between PtcCO₂ and PaCO₂, i.e., the skin's temperature, and the local or general vascular circulation. The purpose of the present investigation was to study in healthy children the effect of breathing carbon dioxide on the simultaneous changes in both PtcCO₂ and PaCO₂ and to determine if the ventilatory response to carbon dioxide can be estimated by both PtcCO₂ and PaCO₂ with a similar accuracy.

Materials and Methods

Eighteen healthy children 3 to 13 years of age (mean, 7 ± 3 years) were tested in the sitting position. Parental consent for each child was obtained. Each wore a nose clip and breathed with a mouthpiece through a pneumotachograph (Fleisch No. 2) connected to a pressure transducer (Schlumberger). The instrumental dead space was equal to 70 ml. Volume was obtained by integration. Both flow and volume were recorded on an ink-projection recorder (Siemens). For continuous analysis of expired carbon dioxide concentration, expired gas was collected from the mouthpiece via a tube (75 cm in length; 2 mm in internal diameter) with a flow sampling of 0.5 L/min. The carbon dioxide analyzer (Beckman LB) was calibrated with 5 percent carbon dioxide. The procedure for calibration (5 percent carbon dioxide) was similar to that for sampling. The concentration of carbon dioxide was continuously recorded, and the carbon dioxide value at 4/5 of the time after the beginning of expiration was considered as reflecting the PaCO₂. The PtcCO₂ was measured with an electrode (Radiometer TCM 20) after the linearity of the electrode response was verified. Before each test the electrode was calibrated at a low point (5 percent carbon dioxide) and a high one (10 percent carbon dioxide). The electrode was placed on the anterior thorax and heated to a temperature of 42°C. The component of the contact liquid used for the measurement was glycerol (1,2,3-propanetriol) (Radiometer).

The protocol for the study was as follows: The children first breathed room air in a steady resting state for 15 minutes (t₁); second,
they breathed 5 percent carbon dioxide for 283 ± 108 seconds (t.) and then returned to room air (t.) The PaCO₂ and PtcCO₂ were recorded during the three periods of the test in all of the children. The PaCO₂ was calculated on at least 15 respiratory cycles. The PtcCO₂ for t. was assessed after a stabilization time of 233 ± 76 seconds. During carbon dioxide breathing, as it has been reported, the increase in PtcCO₂ was delayed compared to PaCO₂. This delay was 239 ± 76 seconds. At t., the PtcCO₂ was taken into account when PtcCO₂ was stable for at least 40 seconds. At t., a stable PtcCO₂ value was obtained after 260 ± 98 seconds. Flow and volume were measured in 11 out of the 18 children. Statistical analysis was performed by the paired t-test.

**RESULTS**

Values for PtcCO₂ and PaCO₂ (in millimeters of mercury) in the 18 children obtained during the three different periods of the test are reported in Table 1. It can be seen that both PtcCO₂ and PaCO₂ increased while breathing carbon dioxide and returned to room air values after cessation of carbon dioxide inhalation. Figure 1 illustrates the relationship between PtcCO₂ and PaCO₂ while breathing room air and 5 percent carbon dioxide. In both conditions, there was a significant relationship between both of these variables: while breathing room air, PaCO₂ = 0.82 PaCO₂ + 19.7 (r = 0.55; p < 0.02), and while breathing carbon dioxide, PtcCO₂ = 0.77 PaCO₂ + 22.5 (r = 0.61; p < 0.01);
However, the ratio of PtcCO₂ over PAcO₂ was significantly lower while breathing carbon dioxide (p < 0.01).

The results for tidal volume (TV), respiratory frequency, and VE while breathing room air and carbon dioxide are reported in Table 2. The increase in VE (in liters per minute) by breathing 5 percent carbon dioxide is plotted against the changes in PAcO₂ (ΔPaCO₂) and in PtcCO₂ (ΔPtcCO₂) in Figure 2. A significant correlation was found between ΔVE and ΔPtcCO₂, i.e., ΔVE = 0.41 ΔPtcCO₂ + 0.44 (r = 0.63; p < 0.01). In contrast, the relationship between ΔVE and ΔPaCO₂ did not reach significance (ΔVE = 0.25 ΔPaCO₂ + 1.64; r = 0.36; p > 0.05).

### Discussion

The present study considered PAcO₂ and PtcCO₂ in healthy children while breathing both room air and 5 percent carbon dioxide. We found a significant decrease in the ratio of PtcCO₂ over PAcO₂ during carbon dioxide breathing. Furthermore, the increase in ventilation during carbon dioxide breathing was significantly correlated to the changes in PAcO₂ but not to the changes in PtcCO₂.

As shown in previous studies performed in sick populations ranging in age from newborn to adulthood, the heated PtcCO₂ values are always higher than the corresponding PAcO₂. The adjustment factor between PtcCO₂ and PAcO₂ was variable and ranged from 1.13 to 1.61. Differences in temperature, electrode, cutaneous properties, and population probably account for these variations. In our present study, PtcCO₂ and PAcO₂ were significantly correlated during both room air and carbon dioxide breathing; however, the ratio of PtcCO₂ over PAcO₂ decreased significantly when breathing carbon dioxide (Table 1). The major factors which are able to change PtcCO₂ at a constant temperature are the cutaneous blood flow, the local production of carbon dioxide, and the transmissibility of carbon dioxide to the electrode. There is no apparent argument for a change in the transmissibility of carbon dioxide to the electrode, since the conditions of measurement were unchanged. A variation in the local production of carbon dioxide by the dermal cells may occur; however, there are no reported data in favor of this hypothesis. Therefore, the remaining factor which can explain the effects of breathing carbon dioxide on PtcCO₂ appeared to be a change in the control of cutaneous blood flow. The control by carbon dioxide of the cutaneous vasomotor tone is not completely clear; however, it appeared that carbon dioxide has at least two effects, a local vasodilator effect and a vasoconstrictor effect via the sympathetic system. Thus, in the conditions of acute hypercapnia, as during carbon dioxide breathing, a competition exists between vasodilator and vasoconstrictor effects of carbon dioxide. In our results a predominance of the vasoconstrictor effect might explain the significant decrease of the PtcCO₂/PAcO₂ ratio during carbon dioxide breathing (Table 1). Moreover, these effects may be different from subject to subject, since the change in this ratio was not identical for all subjects (Table 1). This variation between subjects suggests that

### Table 2—Ventilatory Variables in 11 Healthy Children during Room Air and 5 Percent Carbon Dioxide Breathing

<table>
<thead>
<tr>
<th>Case</th>
<th>TV, L per min</th>
<th>VE, L/min</th>
<th>TV, L per min</th>
<th>VE, L/min</th>
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<td>0.19</td>
<td>44</td>
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<tr>
<td>0.17</td>
<td>28</td>
<td>4.16</td>
<td>0.16</td>
<td>40</td>
</tr>
<tr>
<td>0.17</td>
<td>28</td>
<td>4.76</td>
<td>0.18</td>
<td>44</td>
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<tr>
<td>0.27</td>
<td>20</td>
<td>5.36</td>
<td>0.24</td>
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<tr>
<td>0.39</td>
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<tr>
<td>Mean</td>
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<td>5.60</td>
<td>0.29</td>
<td>34</td>
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</table>

*p<0.05, **P<0.01, ***P<0.001

![Figure 2](http://journal.publications.chestnet.org/pdflatex.png)

**Figure 2.** While breathing 5 percent carbon dioxide, ΔPaCO₂ (left) and ΔPtcCO₂ (right) are displayed on abscissa, while ΔVE is plotted on ordinate. ΔVE is significantly correlated to ΔPaCO₂ (p < 0.01), while there is no significant correlation between ΔVE and ΔPtcCO₂ (ΔVE = 0.25 ΔPtcCO₂ + 1.64; r = 0.36; p > 0.05).
the balance between vasoconstriction and vasodilation of cutaneous blood vessels might be different in each individual. This hypothesis has to be verified by further investigations.

Despite the wide range in ventilatory response to carbon dioxide in a normal population, we observed a significant relationship between the changes in $P_{ACO_2}$ and in $V_E$, while the relationship did not reach the level of significance between the changes in $P_{tCO_2}$ and in $V_E$. The ventilatory response to carbon dioxide did not appear to be measured with accuracy when utilizing the changes in $P_{tCO_2}$, presumably because of the changes in the cutaneous blood flow induced by carbon dioxide breathing.

In summary, in healthy children, we observed that the ratio of $P_{tCO_2}/P_{ACO_2}$ was decreased while breathing 5 percent carbon dioxide when compared to breathing room air. Thus, the present results did not recommend estimating the ventilatory response to carbon dioxide as a function of the changes in $P_{tCO_2}$ instead of the changes in $P_{ACO_2}$. Furthermore, in sick babies and children, alterations in cutaneous blood flow, carbon dioxide production, or the level of arterial partial pressure of oxygen might have an even more significant effect on the variation of $P_{tCO_2}$ than in our normal children.

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