FLUCTUATIONS OF ARTERIAL pH ASSOCIATED WITH THE RESPIRATORY CYCLE IN DOGS

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It is generally accepted that hydron concentration of the circulating arterial blood, serially examined in the same individual, is kept constant within a narrow limit of pH range \(^1-^4\). However, it must be noted that there is some fluctuation in the concentration of alveolar CO\(_2\) during a respiratory cycle, and that this may lead to fluctuation in arterial pH. Though many studies have been made on the acid-base balance in the blood, little attention has been given to this possible fluctuation of arterial pH.

Using our own glass electrode assembly which continuously records the pH of the circulating arterial blood, the present investigation was intended to detect the cyclic fluctuation of pH of the circulating arterial blood by changing rates and depths of respiration.

METHOD

Mongrel dogs were used as experimental animals. Anesthesia was given by injection of sodium pentobarbital. To obtain a slow rate of respiratory frequency, an additional dose of anesthetic was administered intravenously.

An intratracheal tube with a rubber cuff was inserted into the trachea and its outer end was joined to a respiratory valve. Respiratory minute volume was measured by a small Tissot type spirometer. Respiratory movement was recorded kymographically on a smoked paper by means of a Marey tambour connected to the respiratory valve. CO\(_2\) concentration of the inspired air was analyzed by the Haldane method, and plasma CO\(_2\) content was measured by Copp-Natelson's apparatus \(^5\).

The pH of the circulating arterial blood was determined at the femoral artery. The glass electrode assembly used in the present experiment was reported elsewhere \(^6\), but in order to secure more precise recording of potential change of the glass electrode, the following precautions were taken which were not described in the previous paper.

1) Because of the high electrical resistance of the glass electrode membrane (ca. 100 to 200 M\(\Omega\)), prevention of electrical leakage was very important, especially in our country where humidity of the air is always high. A careful measure was taken to avoid dampness of the table on which the experimental animal was placed. Syringe needles and other metallic instruments to be inserted into or to come into contact with the experimental animal were insulated by covering them with vinyl tube or by coating them with an insulating paint.

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2) All the blood vessels, even the very fine ones, were carefully ligated to prevent capillary bleeding resulting from the usage of heparin. Thermo- or electrocauterization for the cut wounds was also done.

3) It was ascertained that the glass electrode used could satisfactorily respond to pH change in the range of 0.01 to 0.03 occurring at a frequency of 20 to 30 per minute.

RESULTS AND CONSIDERATIONS

Cyclic fluctuations of pH of the circulating arterial blood and respiratory curves recorded simultaneously are presented in Fig. 1 to 3 in which various magnitudes of pH fluctuation are seen to depend upon different rates of respiration, ranging from 4.5 to 21.5/min. As is clearly seen in these figures, frequencies of pH changes and of respiratory wave coincided well with each other. It is evident that when these three figures are compared with one another, respiratory frequency has a predominant role in determining the size of pH fluctuation.

It is conceivable that the lesser the respiratory frequency, the higher the amplitude of pH fluctuation. When the respiration becomes less frequent, the time during which CO₂ accumulates in the alveolar space will be so prolonged that alveolar and arterial pCO₂ will be raised more, thus resulting in an increase of arterial cH.

The magnitudes of pH fluctuations related with the respiratory rate under open air breathing are shown in the second column of Table 1. It is seen that the respiratory rates of less than 10/min. are accompanied by significant amount of pH fluctuation.

Using the method of pH determination of the circulating arterial blood, a

![Fig. 1. Cyclic fluctuation of pH of circulating arterial blood and simultaneously recorded respiratory curve. Fluctuating sizes of pH were becoming small as a high respiratory frequency was induced by hypercapnic hyperventilation. Size of fluctuation of pH is ca. 0.07 pH in control period and ca. 0.02 to 0.03 pH in hypercapnic period.](image)
Fig. 2. Cyclic fluctuation of pH of circulating arterial blood and simultaneously recorded respiratory curve. Size of fluctuation of pH is ca. 0.01 pH in control period and ca. 0.008 pH in hypercapnic period.

Fig. 3. Cyclic fluctuation of pH of circulating arterial blood and simultaneously recorded respiratory wave. Size of fluctuation of pH is ca. 0.005 pH in control period and almost zero in hypercapnic period.

Table 1
Respiratory fluctuations of pH and pCO₂ in the circulating arterial blood under open air breathing

<table>
<thead>
<tr>
<th>respiratory rate per minute</th>
<th>size of pH fluctuation observed</th>
<th>size of pCO₂ fluctuation calculated</th>
</tr>
</thead>
<tbody>
<tr>
<td>4–5</td>
<td>0.04 –0.07</td>
<td>4 –9 mmHg</td>
</tr>
<tr>
<td>6–7</td>
<td>0.02 –0.03</td>
<td>2 –4</td>
</tr>
<tr>
<td>8–10</td>
<td>0.01 –0.02</td>
<td>1 –3</td>
</tr>
<tr>
<td>11–13</td>
<td>0.007–0.008</td>
<td>0.7–1</td>
</tr>
<tr>
<td>14–16</td>
<td>ca. 0.005</td>
<td>0.5–0.6</td>
</tr>
<tr>
<td>over 20</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
considerable number of works have been made by various investigators\textsuperscript{7-14}. Most of them agreed in that arterial pH was kept fairly constant within the range of their experimental error whenever the experimental animals were put in the steady state of respiration, but they made no reference to the systematic relationship between cyclic fluctuation of arterial pH and respiratory frequency. Only Haessler\textsuperscript{15} and Hesser\textsuperscript{16} made a few remarks in their reports.

Although the respiratory frequency was the most important factor in determining the size of pH fluctuation, we sometimes experienced variation in pH fluctuation under the same respiratory frequency. Fig. 4 is presented as an example of such cases. In this figure the size of fluctuation of pH was diminished by CO\textsubscript{2} inhalation though the respiratory frequency remained unchanged. In this case of experiment, the difference of CO\textsubscript{2} content between the alveolar and the inspired air was reduced to one fourth by CO\textsubscript{2} inhalation whereas the volume of inspired air introduced into the alveolar space increased 4.3 times. This seems to be why the presence of CO\textsubscript{2} in the inspired air did not diminish the size of pH fluctuation during an inspiratory cycle. The fluctuation of alveolar pCO\textsubscript{2}, on the other hand, depends upon the amount of accumulated CO\textsubscript{2} which is provided from the pulmonary capillary blood to the alveoli. Therefore, the more the alveolar spaces participate in ventilation by deeper breathing, the lesser the pCO\textsubscript{2} fluctuation will occur. Since CO\textsubscript{2} output did not change so much by CO\textsubscript{2} inhalation, we assumed that this diminished size of pH fluctuation must be ascribed to the deepening of breathing.

![Fig. 4. Cyclic fluctuation of pH of circulating arterial blood and simultaneously recorded respiratory curve. Size of fluctuating pH was reduced to about half by CO\textsubscript{2} inhalation. Respiratory rate was maintained at the same level as in the control period.](image)

As above stated, these fluctuations of arterial pH originate from those of alveolar, hence arterial, pCO\textsubscript{2}. So, the fluctuations of arterial pCO\textsubscript{2} under various respiratory frequencies can be calculated from arterial pH and plasma
CO₂ content on the basis of Henderson-Hasselbalch's equation \((pK' = 6.10)\). These are shown in the third column of Table 1. It must be noted that these values represent the fluctuations of the arterial blood and not of the alveolus itself. The CO₂ in the pulmonary capillary blood, equilibrated with each alveolar CO₂, will be mixed and averaged as it comes from the lung to the left heart ventricle. So the size of fluctuation of arterial pCO₂ will be smaller than that of the alveolar pCO₂ actually occurring in the lung alveoli. In fact, the fluctuation of alveolar pCO₂ itself which DuBois, Britt and Fenn\(^{17}\) computed in normal human subject by application of the Fick principle is far greater than the one deduced by us.

Granted that in a human subject the ratio of alveolar ventilation to pulmonary blood flow and other factors affecting the gas exchange for CO₂ do not differ much from those of the normal dog, the cyclic fluctuation of arterial pH and pCO₂ in a human subject breathing normally will be in the order of 0.005 and 0.5 to 0.6 mmHg respectively.

The pH determination with the shed blood, the only method applicable to the human subject, has an accuracy at most of ±0.01 pH. Therefore, it would be unable to detect such small fluctuation of pH, if any, by the available methods published so far.

**SUMMARY**

Using the glass electrode assembly connected with the femoral artery in dogs, the cyclic fluctuation of pH of the circulating arterial blood was observed under varying rates and depths of respiration. The frequency of fluctuation coincided with the respiratory rate, and the size of fluctuation was magnified as respiratory frequency was decreased. When the breathing was increased in depth without changing the frequency by CO₂ inhalation, a smaller range of pH fluctuation was resulted.

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**REFERENCES**