Acid-base equilibrium in the blood of sheep

L. Gattinoni[1] and M. Samaja[2]

Laboratory of Technical Development and Clinical Hematology Branch, National Heart, Lung and Blood Institute, National Institutes of Health, Bethesda (Maryland 20014, USA), 22 November 1978

Summary. The acid-base equilibrium in the blood of sheep is different from that of human blood mainly because of a lower concentration of 2,3-DPG. A nomogram relating pH, pCO_2, total CO_2 content and base excess has been developed.

Recently, we described the oxygen affinity pattern in the blood of sheep[3], which was found to be quite different from that of human blood. Some differences between the 2 species should be expected as regards the acid-base status also, mainly because of different concentrations of 2,3-diphosphoglyceric acid (2,3-DPG), which is known to be lacking in sheep[4]. The aim of this work is to investigate the in vitro relationship between pH, pCO_2, total CO_2 content and base excess (BE) and to provide a tool for computing the acid-base equilibrium in the blood of sheep.

Experimental titration curves for oxygenated sheep blood are shown in figure 1 (solid lines). The zero BE value, as defined by Siggaard-Andersen[5], was arbitrarily set at pH 7.4 and pCO_2 40 mm Hg (the temperature is always 37 °C) in order to facilitate the comparison with human blood (dashed lines), although the normal pH and pCO_2 values are given at 7.44 and 45 mm Hg, respectively[6], for a healthy adult sheep. As regards the acid pH range, the curves of human blood are significantly lower than those of sheep blood at corresponding pCO_2. It can be seen that sheep blood has a lower buffering power (i.e. the derivative d(BE)/d(pH) vs. pH (not shown) as defined by Van Slyke and Sendroy[7]) than does human blood in the pH range below 7.3. This can be attributed to the low level, in sheep, of 2,3-DPG, which has a pK of about 7.1[5] and therefore affects very much the buffering power in the low pH range in human blood. The state of oxygenation of hemoglobin does not seem to affect the buffering power, since no significant difference in the derivative was found between oxygenated and deoxygenated blood (not shown).

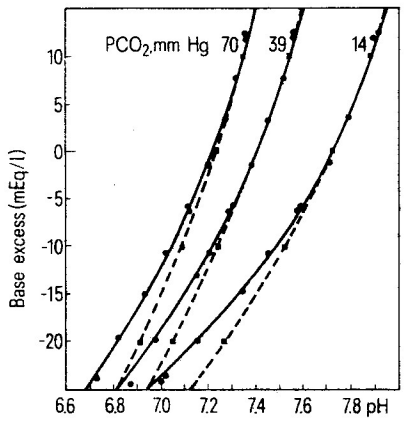

Fig. 1. Solid lines are the titration curves of heparinized blood from 4 healthy adult Dorset sheep. 1 ml of blood was equilibrated at 37 °C with selected gases at 5 different CO_2 tensions (namely, 70, 49, 39, 28, and 14 mm Hg; 3 only shown), balance O_2, or N_2 (not shown), in an IL 237 tonometer (Instrumentation Lab., Lexington, Mass.), and the pH measured in an IL 213 pHmeter (Instrumentation Lab.). A range of pH was achieved by adding to the blood various amounts of acid (0.2 N HCl) or base (0.2 N NaOH) in the constant volume of 0.1 ml (balance with normal saline solution) in order to keep a constant hematocrit. Dashed lines are the titration curves of oxygenated human blood calculated from the data of Siggaard-Andersen[5] at the sample pCO_2.

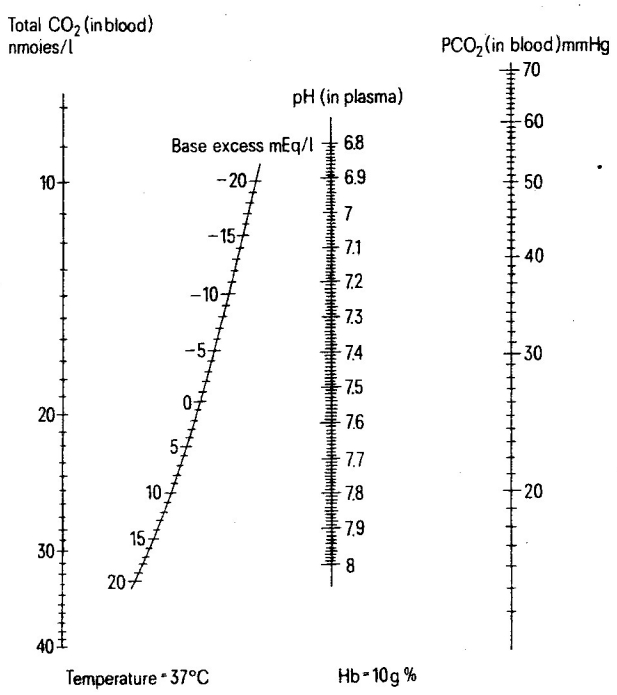

Fig. 2. Nomogram relating total CO_2 content, base excess, pH and pCO_2 in the whole blood of sheep. It is valid for any hemoglobin species and concentration within the physiological range. Total CO_2 content, on the other hand, is valid only when the hemoglobin concentrations is 10 g/dl.

At fixed pH, BE vs. pCO_2 forms a series of straight lines:

$$BE = A + B \times pCO_2. \quad (1)$$

A and B could be thought to be parabolic functions of pH, so that:

$$A = -13.09 \times (pH-7)^2 + 21.02 \times (pH-7) - 26.52 \quad (2)$$

$$B = 1.24 \times (pH-7)^2 + 0.36(pH-7) + 0.18. \quad (3)$$

BE can therefore be computed at any given pH in the range 6.8 – 7.6 and pCO_2 in the range 14–70 mm Hg by substituting equations 2 and 3 in equation 1. The values of the parameters were estimated by the least square rule and the root mean square error in calculating BE by such a procedure is 0.67 BE units, when expressed in meq/l. Part of figure 2 is a graphical representation of the previous functions, valid at 37 °C and any hemoglobin concentration.

In another set of experiments, total CO_2 concentrations were determined at 5 pCO_2 and varying pH, on both oxygenated and deoxygenated blood, by the same way described in the legend of figure 1, except that the volumes of blood and of the balancing solutions were 5 ml and 0.5 ml, respectively. A standard Van Slyke procedure[8] was used to calculate the total concentration of CO_2. At fixed pH, total CO_2 content in whole blood, at a hemoglobin concentration of 10 g/dl and 37 °C was found to be a linear function of pCO_2:

$$\text{total } CO_2 = B \times pCO_2. \quad (4)$$

This equation can be combined with the following one:

$$\log(\text{total } CO_2/pCO_2) = 0.91 \times pH - 6.99 \quad (5)$$

to give a relationship connecting three parameters:

$$\text{total } CO_2 = pCO_2 \times 10^{(0.91 \times pH - 6.99)}. \quad (6)$$

The root mean square error is 0.49 total CO_2 units, when expressed in mmoles/l. Equation 6 is also represented in the left part of figure 2, but it must be recalled that it refers to blood with a hemoglobin concentration of 10 g/dl.

1 Present address: Institute of Anesthesiology, University of Milan, via F. Sforza 35, I-20122 Milano (Italy).
2 Present address: Cattedra of Enzymology, University of Milan, via Celoria 2, I-20133 Milano (Italy).
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