The Acid-Base Status of Arterial and Various Abdominal Venous Blood in Sheep

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Abstract The present experiment was carried out to establish the acid-base status of arterial and various abdominal venous blood in sheep and to discuss the respiratory alkalosis-like characteristic in this animal. The abdominal veins of sheep had a pH (or P_{CO_2}) gradient: the mean pH was lowest in the right ruminal venous blood ($pH=7.129 \pm 0.206$) and gradually increased with approach to the vena cava inferior ($pH=7.363 \pm 0.065$), while the P_{CO_2} changed in an opposite manner (from 82.6 ± 31.7 to 40.1 ± 5.0 mmHg). The results in the right ruminal venous blood might be due to the neutralization of volatile fatty acids absorbed through the ruminal epithelium by HCO_3^- in the blood, resulting in higher P_{CO_2} and lower pH. Furthermore, the mean values of pH in arterial and venous blood of sheep seemed higher than those of the cow or human, mainly because of a lower P_{CO_2} . The physiological role of this characteristic in sheep is discussed.

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Sheep exhibit some remarkable differences in the blood acid-base balance compared with monogastric animals. They seem to be in a state of mild respiratory alkalosis even at rest, since their blood shows a lower P_{CO_2} and a higher pH than human blood^{1,2)}. In addition, the pH and the concentration of HCO_3^- (but not P_{CO_2}) in blood markedly decrease during eating as a result of secretion of HCO_3^- -rich saliva^{2,3)}. In the present study, we investigated the acid-base status of sheep in the carotid artery and various abdominal veins, in order to cast light on the physiological significance of the relatively low P_{CO_2} and high pH. The results are also compared with the published values of blood in the cow⁴⁾ and human^{5,6)}.

Materials and Methods

Fifteen adult Merino sheep of either sex were surgically fitted with a left carotid arterial loop. Blood sampling was carried out through catheters inserted into the carotid artery and the jugular vein. In this case, rectal temperature was also measured with a thermometer inserted 10 cm into the rectum. Three of the fifteen sheep were used for mixed venous blood sampling via polyvinyl tubing inserted into the right ventricle of the heart through the right jugular vein. Another six sheep were anaesthetized with an intravenous injection of pentobarbital sodium (25 mg/kg of body weight), and blood samples (1 ml for each sample) were taken from the vena cava

inferior, hepatic vein, portal vein, right ruminal vein and carotid artery. The whole procedure of the experiment was finished within two hours. The blood was drawn into a syringe containing sodium heparin and placed in ice water until measurements were carried out.

Jugular venous blood samples from thirty lactating and non-lactating Holstein cows were also taken for comparison with those of sheep. Animals were not permitted to eat for twenty hours before experiments, but had free access to water.

The blood pH and the P_{CO_2} were measured with a blood gas analyzer (type PHM 72, Radiometer, Copenhagen) at 37°C. The concentrations of HCO_3^- in plasma, $[HCO_3^-]$, were calculated from the SIGGAARD-ANDERSEN alignment nomogram⁷⁾. The total CO_2 concentrations in the whole blood, $tCO_2(W)$, were measured by a gasometric method⁸⁾. The hemoglobin concentrations were measured with a hemoglobin measurement kit (Hemoglobin-Test, Wako Pure Chem., Tokyo). In certain instances, the differences in mean value were analyzed by the Student's *t*-test.

Results and Discussion

The acid-base parameters of various abdominal veins and the carotid artery in sheep are summarized in Table 1. It is apparent that the abdominal venous blood had a gradient in its pH. That is, the pH was lowest in the right ruminal venous blood and gradually increased with approach to the vena cava inferior, while the P_{CO_2} showed an opposite tendency.

The reasons why the abdominal blood of sheep showed such a gradient may be explained as follows. The volatile fatty acids which are absorbed into the ruminal venous blood through the ruminal epithelium are neutralized by HCO_3^- , resulting in higher P_{CO_2} and lower pH. High P_{CO_2} of ruminal blood would be gradually reduced by the inflow of lower P_{CO_2} blood with approach to the vena cava inferior. If this

Table 1. Acid-base status of abdominal venous blood in sheep

		pH	P_{CO_2} (mmHg)	HCO_3^- (mEq/l)
Vena cava inferior (n=5)	mean	7.363	40.1	22.4
	±SD	0.065	5.0	2.1
Hepatic vein (n=5)	mean	7.385	40.6	21.7
	±SD	0.043	7.1	1.5
Portal vein (n=5)	mean	7.274	51.2	22.9
	±SD	0.088	8.8	1.5
Right ruminal vein (n=6)	mean	7.129	82.6	25.0
	±SD	0.206	31.7	3.8
Carotid artery (n=6)	mean	7.462	31.1	22.3
	±SD	0.025	5.7	1.7

Acid-base Status of Sheep Blood

Table 2. Acid-base parameters in blood of sheep and cow

	Jugular venous blood				Mixed venous blood			Carotid arterial blood			
	Hb	pH	Pco ₂	HCO ₃ ⁻	pH	Pco ₂	HCO ₃ ⁻	pH	Pco ₂	HCO ₃ ⁻	tCO ₂ (w)
	(g/dl)		(mmHg)	(mEq/l)		(mmHg)	(mEq/l)		(mmHg)	(mEq/l)	(mmol/l)
Sheep mean	10.6	7.445	37.0	25.5	7.429	37.4	24.8	7.479	29.8	22.3	21.91
±SD	1.1	0.022	3.0	2.9	0.008	1.7	1.6	0.015	2.1	1.5	1.10
(n)	(15)				(3)			(15)			
Cow mean	10.9	7.389*	49.6*	30.1*							
±SD	1.3	0.014	4.0	2.3							
(n)	(30)										

The means with superscript (*) are significantly different from those of sheep ($P < 0.01$).

view is acceptable, a similar gradient to that found in sheep might also be observed in other ruminal animals.

The acid-base parameters in jugular venous, mixed venous and carotid arterial blood of sheep are shown in Table 2 with the data for the jugular vein in the cow.

In jugular venous blood, the pH of sheep was significantly higher than that of the cow ($P < 0.01$). This might be explained by the lower Pco₂ in sheep, since pH was higher despite lower [HCO₃⁻].

The pH of mixed venous blood in sheep was compatible with that previously reported by PARER *et al.* (7.420~7.495)¹¹. They pointed out that the pH difference between mixed venous and carotid arterial blood in sheep was larger than that in the human and suggested that this might be explained by the lower buffering power of sheep blood because of its lower hemoglobin concentration. However, the hemoglobin concentration seems not to be so important to the higher pH of sheep blood, because the pH and Pco₂ of blood in sheep are significantly different from those in the cow in spite of the almost similar hemoglobin content.

POULSEN and SURYNEK⁴⁾ reported that the pH, Pco₂ and [HCO₃⁻] of arterial blood in the cow were 7.429±0.016, 34.3±1.8 mmHg and 23.7±1.1 mEq/l, respectively. Furthermore, SIGGAARD-ANDERSEN and his co-workers^{5,6)} reported that those parameters in human arterial blood were 7.405±0.015, 39.3±2.7 mmHg and 24.7±1.2 mEq/l, respectively. These results suggest that the pH of arterial blood in sheep is higher than those in the cow and human. This must be due to a low Pco₂ in sheep in spite of the similar content of [HCO₃⁻] in these three species.

If sheep had hyperventilated and reduced the Pco₂, tCO₂(W) should also be reduced as a result of compensatory action. However, tCO₂(W) in sheep was approximately similar to that in human arterial blood as previously reported by SIGGAARD-ANDERSEN *et al.*⁶⁾.

The ratio of total CO₂ in arterial blood of sheep to that in the human (22.30±1.20 mmol/l)⁶⁾ is 0.98 and the same ratio of physically dissolved CO₂ is 0.79. This means that the dissolved CO₂ content in sheep plasma is smaller than that in the

human, though the total CO₂ content is almost similar.

As the rectal temperature of sheep is higher ($38.8 \pm 0.7^\circ\text{C}$) than the 37°C at which blood parameters were measured, the pH value in sheep should be corrected by means of the SIGGAARD-ANDERSEN⁹⁾ equation. The corrected value of pH in the arterial blood is 7.520 ± 0.015 , which is higher than that of human blood (7.405 ± 0.015)⁵⁾.

Recently it was found that 2,3-diphosphoglyceric acid (2,3-DPG), which was known to be important for oxygen transport, was scarce in the red blood cells of sheep¹⁰⁾. SAMAJA and GETTINONI^{11,12)} pointed out that the oxygen affinity pattern and the acid-base equilibrium in the blood of sheep were different from those of the human because of the low concentration of 2,3-DPG. If the blood Pco₂ in sheep was higher than that in the human, their oxygen equilibrium curve would shift to the left of that of the human. This means that hemoglobin could not easily liberate oxygen to the tissue, suggesting a disadvantage in oxygen transport for sheep. Therefore, the lower level of Pco₂ in sheep might improve oxygen transport in spite of the lower level of 2,3-DPG, since this compound increases while Pco₂ decreases the BOHR coefficient¹³⁾. The deficiency of 2,3-DPG in hemoglobin might assist this animal to keep a lower Pco₂.

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綿羊の血液における酸-塩基平衡

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綿羊の血液は，人間などと比較して，呼吸性のアルカローシスの傾向を示す．今回の実験では，安静状態にある綿羊の頸動静脈血および腹腔内の種々の静脈血の酸-塩基平衡に関するパラメーターを測定し，綿羊の血液の特異性について検討した．6頭のメリノ種綿羊を麻酔下で開腹し，右第一胃静脈，門脈，肝静脈および後大静脈から採血した．頸動静脈血は，別の15頭の左頸動脈ループ装着綿羊から採取し，その内の3頭からは右心室にカテーテルを挿入して混合静脈血を採取した．また，綿羊と比較するために，30頭のホルスタイン種泌乳牛および乾乳牛から頸静脈血を採取した．採取した血液は，血液ガス分析装置を用いて，pH および P_{CO_2} を測定し， HCO_3^- 濃度はモノグラムから算出した．綿羊の腹腔内静

脈血には明らかな pH（もしくは P_{CO_2} ）勾配が認められた．すなわち，右第一胃静脈血の pH は， 7.129 ± 0.206 と最も低く，門脈，肝静脈と上行するに従い上昇する傾向を示した．逆に， P_{CO_2} は第一胃静脈血で最も高く（ 82.6 ± 31.7 mmHg），後大静脈血で最も低かった（ 40.1 ± 5.0 mmHg）．この原因として，第一胃粘膜を通して吸収された VFA が血中の HCO_3^- により中和され，その結果増加した P_{CO_2} が pH を低下させることが考えられた．また，綿羊の頸動静脈血の pH は，乳牛や人間と比較して高い傾向にあり，この原因は綿羊血液の P_{CO_2} 値が低いことによると考えられた．

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