Effect of Constant Magnetic Field on the Binding of Carbonic Gas by Blood *In Vivo*

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Exposure of blood to magnetic field modifies the rate of CO_2 removal. It is hypothesized that this phenomenon is due to change in pH caused by magnetic field and Bohr effect.

Key Words: *magnet; blood; oxygenation; carbonic gas*

Previously [1-3], we showed that exposure of peripheral blood to constant magnetic field (CMF) in an extracorporeal circuit prolongs the survival period in fatal hypoxia [2], which results from increased oxygen capacity of blood [1,3]. The phenomenon of greater oxygen binding under the effect of CPM may be useful in surgery and resuscitation; however, it is important to know how CPM affects CO_2 removal from the blood. This knowledge will also contribute to the understanding of the mechanisms underlying the effects of CMF on blood properties.

MATERIALS AND METHODS

Three series of experiments were performed on 38 mongrel dogs of both sexes (body weight 7-10 kg). In the firsts series, the dogs were transferred to artificial ventilation (an RO-6 apparatus) under ketamine (3-4 mg/kg) and ditiline (1 mg/kg) anesthesia. The femoral and jugular veins were shunted for blood transfer (an AT-1 pump) from the lower vena cava to the right atrium at a flow rate of 20-25 ml/min×kg. In 20 experiments the extracorporeal circuit was exposed to PCM (flux density 0.5 T). In 18 experiments (control) magnetic field was absent. In each experiment blood was pumped through the circuit for 20 min, after which blood samples were collected for determination of Pco_2, So_2, and pH.

In the second series, a membrane oxygenator was connected to the circuit consecutively to the pump and magnetic field cuvette; the inlet and outlet tubes were shunted. In each experiment, after filling with blood the circuit was disconnected from blood vessels by clamping the inlet and outlet tubes, the shunt was opened, the pump was switched on, and blood started circulating in the circuit consisting of cuvette with a magnet, pump, and oxygenator. Oxygen was supplied to the oxygenator as soon as the pump was switched on. Blood samples for determination of Pco_2, So_2, and pH were collected after 5 min of circulation in the circuit. In four experiments blood was and in four others (control) was not exposed to CMF.

As in the second series, the circuit contained the cuvette and oxygenator and lacked the shunting tube. In each experiment blood was pumped from the vena cava to the right atrium through the cuvette and oxygenator. Blood samples for Pco_2, So_2 and pH determination were collected at the input and output of the oxygenator. In 37 experiments the cuvette was exposed to CMP and in 36 control experiments it was not. Blood was bubbled with oxygen through the oxygenator. In 11 experiments with 6 controls blood was bubbled with oxygen, and in 10 experiments with 16 controls it was not bubbled.

In all series blood parameters were determined in an AME-1 analyzer (Radiometer), Elema oxymeter, and Mingograf-82. The results were analyzed using statistical methods.

RESULTS

When blood was saturated with oxygen through the lungs or oxygenator, Pco_2 decreased under the effect

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TABLE 1. Parameters of Blood Circulating Blood Vessels after Oxygen Breathing for Two Minutes *(M±m)*

Experimental conditions	Artery			Vein		
	Pco_2, mm Hg	So_2, %	pH	Pco_2, mm Hg	So_2, %	pH
Without CMF	24±6	99.8	7.360	33±7	77	7.334
With CMF	22±5	99.7	7.340	28±5	79	7.320

of CMF (Tables 1 and 2). The difference between Pco_2 at the input and output of the oxygenator upon exposure of blood to magnetic field (magnetization) increased when the blood was bubbled with oxygen and decreased when it was bubbled with air (Table 3). It can be concluded from these findings that blood magnetization and bubbling with oxygen increase and bubbling with air decreases the rate of CO_2 removal. Lower rate of CO_2 removal upon bubbling with air indicates that magnetization hampers removal of CO_2. The higher rate of CO_2 removal may be due to Holdane effect leading to replacement of CO_2 as a result of additional oxygen binding to hemoglobin exposed to magnetic field, which occurs under these conditions [3].

The removal of CO_2 from blood is usually accompanied by pH increase, since it is associated with decomposition of bicarbonates:

$$CO_2+H_2O \leftrightarrow H^++HCO_3^-, \qquad (1)$$

leading to a decrease in the concentration of hydrogen ions. When blood is oxygenated via lungs, magnetization provides additional removal of CO_2 and pH decrease (Table 1). When blood is oxygenated though the membrane oxygenator, magnetization decreased Pco_2 by 5 mm Hg and increased pH by 0.01 (Table 2). Bubbling with oxygen without magnetization decreased Pco_2 by 5 mm Hg and increased pH by 0.028 (Table 3). Consequently, as in the first series, in the second series of experiments magnetization lowers pH. From these findings it can be concluded that CMF or additional binding of oxygen to magnetized hemoglobin causes the release of H^+.

Magnetization of blood without bubbling of the oxygenator, i.e., without oxygenation and CO_2 removal, increases pH by 0.014 (Table 3). Hence, the influence of CMF on blood causes the binding of H^+, which may inhibit the removal of CO_2 upon magnetization, shifting reaction (1) to the right.

TABLE 2. Parameters of Blood Corculating in Extracorporeal Circuit with a Membrane Oxygenator Bubbled with Oxygen *(M±m)*

Experimental conditions	Pco_2, mm Hg	So_2, %	pH
Without CMF	11.4±1.0	100	7.61
With CMF	6.2±1.1	100	7.62

Magnetization with oxygenation by air, when CO_2 is not removed and additional oxygen is not bound, decreases pH by 0.011. Presumably, this pH change is a result of the 0.0144 increase under the influence of CMF and the 0.025 decrease due to an increase in Pco_2 by 1.4 mm Hg.

Magnetization with oxygen bubbling, when CO_2 is removed and additional oxygen is bound, increases pH by 0.017. This pH change may be due to the 0.014 increase caused by CMF, the 0.035 increase resulting from Pco_2 reduction by 2 mm Hg, and the 0.032 decrease caused by the binding of additional oxygen. Consequently, the binding of additional oxygen is accompanied by H^+ release similar to Bohr effect in nonmagnetized blood. The release of H^+ may accelerate the removal of CO_2, shifting reaction (1) to the left.

In the third series air was used for blood oxygenation in the extracorporeal circuit. Additional oxygen did not bind to hemoglobin in the lungs, suggesting that the rate of CO_2 removal decreases, while pH rises as a result of increase in Pco_2. In fact, in all experiments CMF increased Pco_2 and decreased pH at the input of the oxygenator (Table 3). The increase in Pco_2 confirms the increase in the rate of CO_2 removal under the influence of CMF.

The decrease in pH depended on the mode of oxygenation. When air was used for bubbling and blood was exposed to CMF, the 2.5 mm Hg increase in Pco_2 at the input of the oxygenator was attended by a pH decrease by 0.007. When oxygen was used, the increase in Pco_2 by 3 mm Hg coincided with a decrease in pH by 0.044. Consequently, bubbling with oxygen caused a significant additional reduction in pH upon exposure of blood to CMF. This confirms the release of H^+ upon binding of additional oxygen in the oxygenator.

Based on these findings, we propose the following model. Exposure of peripheral blood to CMF lowers the concentration of H^+, which shifts reaction (1) to the right and decreases the rate of CO_2 removal on breathing air. The binding of additional oxygen (bubbling with oxygen) releases H^+, which shifts reaction (1) to the left and accelerates removal of CO_2.

TABLE 3. Blood Parameters and Their Difference and the Input and Output of Oxygenator Included into Extracorporeal Circuit *(M±m)*

Experimental conditions			Pco_2, mm Hg	ΔPco_2, mm Hg	So_2, %	ΔSo_2, %	pH	ΔpH
Without bubbling								
	without CMF	input	37.6±2.9		55.8		7.246±0.027	0.003
		output	37.8±2.9	+0.27±0.53	64.9	9.1	7.249±0.031	+0.007
	with CMF	input	45.2±4.2		60.1		7.190±0.042	0.017
		output	44.8±4.6	-0.35±0.35	67.1	7.5	7.207±0.039	+0.029
Bubbling with air								
	without CMF	input	30.1±2.1		69.0		7.316±0.013	0.053
		output	23.1±0.7	-7.0±2.0	85.1	16.1	7.369±0.019	+0.014
	with CMF	input	32.6±2.6		67.6		7.309±0.023	0.042
		output	26.9±1.7	-5.6±1.3	84.0	16.4	7.351±0.012	+0.010
Bubbling with oxygen								
	without CMF	input	28.7±1.8		82.7		7.319±0.023	0.028
		output	23.7±2.6	-5.0±0.6	101	18.3	7.346±0.025	+0.003
	with CMF	input	31.7±1.8		82.8		7.275±0.027	0.045
		output	24.7±1.5	-7.0±0.8	101.2	18.4	7.320±0.030	+0.007

The following hypothesis may explain the effect of CMF on the acidic properties of hemoglobin. Under the influence of magnetic field in some hemes the bond between nitrogen and iron atoms is disrupted, and H^+ binds to nitrogen. As a result active hemoglobin is formed. Additional oxygen binds to a free bond of the iron atom. This releases H^+ as a result of Bohr effect.

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