microviscosity of PL membrane lipids [3, 4]. There is evidence to show that this ratio and the cholesterol concentration was increased [3] in animals on diets with a low LA content, whereas the opposite changes are found on diets rich in LA [3].

Diets with diametrically opposite LA content may thus possess antithrombogenic or thrombogenic properties on account of changes in the physicochemical characteristics of the PL membranes and sensitivity of PL to Ca^{++}.

LITERATURE CITED

1. Kh. M. Markov and V. V. Atrokhov, Vorp. Med. Khim., 30, No. 2, 47 (1984).
2. E. Ya. Pozin, E. G. Popov, and Z. A. Gabbasov, "Investigation of the redistribution of intracellular calcium in platelets during aggregation and the reaction of their release," Byull. Vses. Kardiol. Nauch. Tsentra, 4, No. 2, 55 (1981).
3. E. Berlin, E. L. Mafusik, and C. Young, Lipids, 15, No. 8, 604 (1980).
4. A. C. Beynen, Ernähr,-Umschau, 29, No. 4, 119 (1982).
5. R. W. Colman, Ann. Intern. Med., 82, 839 (1975).
6. M. B. Feinstein, G. A. Rodan, and L. S. Culter, Platelets in Biology and Pathology, Vol. 2, Amsterdam (1981), pp. 437-472.
7. G. N. Gerge, R. M. Lyons, and R. K. Morgan, Platelets, Cellular Response Mechanisms and Their Biological Significance, New York (1980), pp. 81-94.
8. S. H. Goodnight, W. S. Harris, N. E. Connor, et al., Atherosclerosis, 2, No. 2, 87 (1982).
9. G. Hornstra, A. Chait, M. J. Karsonen, et al., Lancet, 1, 1155 (1973).
10. J. A. Jakubowski and N. G. Ardlie, Atherosclerosis, 31, 335 (1978).

TERMINATION OF ANOXIA BY APNEIC OXYGENATION WITH EXTRAPULMONARY MEMBRANE CO_2 REMOVAL

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The method of apneic oxygenation with extrapulmonary CO_2 elimination is used in the treatment of respiratory failure [3-10]. The method essentially enables the body to carry out gas exchange while the lungs remain relatively at rest, with favorable effects on their treatment. The combined use of pulmonary and extrapulmonary routes of CO_2 elimination and O_2 intake also has advantages. Oxygen insufflation into the lungs under low pressure, combined with oxygenation of the blood in a membrane oxygenator (MO), ensures an adequate oxygen supply to the body, and excludes barotrauma and other detrimental consequences of artificial ventilation of the lungs (AVL). Extrapulmonary removal of CO_2 with the aid of a MO can be done with small perfusion volumes through this device, so that the safe periods of perfusion can be considerably lengthened. Some aspects of the gas exchange when anoxia is terminated by this method have been inadequately explained.

This paper describes a study of the gas exchange of animals during apneic oxygenation and extrapulmonary elimination of CO_2, using an improved Sever MO [2] with small perfusion volumes.

EXPERIMENTAL METHOD

Three series of experiments were carried out on 34 dogs of both sexes, weighing 14-18 kg. After premedication with pentobarbital (20 mg/kg) anesthesia was maintained by periodic intravenous injections of hexobarbital (10 mg/kg) and heparin was given in an initial dose

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of 8-10 mg/kg, followed by 0.5 mg every 30 min. Succinylcholine was used for muscle relaxation (initial dose 20 mg, followed by 5 mg on the appearance of signs of restoration of breathing) and moist oxygen was supplied (200-250 ml/min) through an endotracheal tube under a pressure of 5-8 cm water (open circuit: O_2 source—lungs—outlet pipe with throttle and manometer). In the corresponding series an arteriovenous shunt was formed between the femoral artery and vein (AVS) and a venovenous shunt between the femoral and jugular veins (VVS). The volume velocity of perfusion (VVP) through the shunt varied with the stages of the investigation: 16.0 ± 3.80 — 38.8 ± 3.90 ml/min·kg for the AVS and 31.6 ± 3.87 — 38.0 ± 2.39 ml/min·kg for the VVS. The internal diameter of the cannulas for taking arterial and venous blood did not exceed 3 mm, and for returning blood 3.4-4 mm. In all series the MO was included in the circuit of the shunts. Under AVS conditions blood flowed through MO of its own accord, but with VVS the roller pump unit of the ISL-4 apparatus was used to transport the blood around the closed circuit (it was located before the MO). To remove CO_2 from MO, O_2 or air was passed through it with a volume velocity of gas flow (VVGF) of 1 to 10 liters/min.

In series I apnea and an AVS were created and MO was blown through with oxygen (12 experiments) or air (7 experiments); in series II apnea and a VVS, and MO was blown through with oxygen (7 experiments) or air (4 experiments); in series III bradypnea (4 breaths per minute) and AVS were created, and MO was blown through with oxygen (4 experiments). The working parameters of MO were: priming volume 100 ml per 1 m^2 of surface, rated capacity of one unit 1000 ml/min. The total capacity of the extracorporeal system was 350 ml with AVS and 500-550 ml with VVS. The experimental conditions included normothermia and hemodilution, and no donated blood was used. The perfusion system was filled with Ringer—Locke, 5% glucose, and rheopolyglucin solutions. Gas exchange, intracorporeal and in MO, was estimated as pO_2 and pCO_2 in the alveolar air, the partial pressures of O_2 and CO_2 and the hemoglobin saturation with O_2 in arterial and venous blood, and the acid-base balance (ABB). The ventilation minute volume (VMV) of gas and blood passing through MO was determined at the same time. An AME-1 analyzer, OS M Oximeter (from Radiometer, Denmark), an MKh 6202 mass spectrometer, and an RKE-2M blood flowmeter were used. The various parameters were investigated under anesthesia, during spontaneous breathing or AVL, after 15 min of apnea and insufflation of O_2 into the lungs without MO, 1, 2, and 3 h after MO began to be connected, and after its disconnection. The data were subjected to statistical analysis.

EXPERIMENTAL RESULTS

Previous investigations showed [3, 4] that during insufflation of O_2 under conditions of apnea or bradypnea the oxygen balance of the body is maintained for quite a long time at a satisfactory level, but that hypercapnia quickly develops and substantial shifts of the ABB of the blood take place. It was also shown that hypercapnia under conditions of apneic oxygenation is tolerated more easily than during anoxia, but the metabolic disturbances which arise nevertheless lead to death of the animals 1.5-2 h after the beginning of apnea.

The results of the present investigation also were very convincing: after 15 min of insufflation of O_2 into the lungs under apneic conditions, before connection of MO p_aCO_2 and p_vCO_2 rose from 37.5 ± 2.06 and 42.6 ± 1.29 to 80.1 ± 4.42 and 84.8 ± 3.69 mm Hg, respectively, BE (base excess) fell to 11.9 ± 0.64 mmoles/liter, and pH fell to 7.06, although p_aO_2 and p_vO_2 were maintained at high levels (231.0 ± 20.60 and 70.5 ± 6.21 mm Hg, respectively).

Whatever the method of connection of MO (AVS or VVS), its use enables the gas exchange of the body to be maintained without significant disturbances for a long time (3 h in these experiments). A combination of insufflation of O_2 into the lungs during apnea or bradypnea with gas exchange in MO results in a stable and high blood O_2 concentration. With AVS, p_aO_2 was maintained throughout this time between 283.0 ± 37.53 and 369.0 ± 64.82 mm Hg, and with VVS between 254.4 ± 11.11 and 279.0 ± 10.0 mm Hg. During ventilation of MO with oxygen the pO_2 level in the outflowing blood was significantly higher than when air was blown through MO, and it lay between limits of 279.0 ± 10.0-403.0 ± 39.92 and 109.3 ± 6.69-166.7 ± 6.92 mm Hg, respectively ($p < 0.05$). Thus, ventilation of MO with oxygen to eliminate CO_2 from it can act as an additional source of O_2 (besides insufflation) in respiratory failure. At the same time, it must be recalled that there is a direct connection between the gas exchange in MO, pO_2 of the arterial blood, and the alveolar gas composition. During perfusion this calls for careful monitoring of the blood gas composition, for a considerable rise of pO_2 of the arterial blood will increase the risk of the toxic action of O_2 insullfated into the lungs. When MO is ventilated with air, insufflation even of pure moist oxygen into the lungs under

low pressure (5-8 cm water) does not entail such a risk, for under these circumstances pO_2 in the alveolar air is maintained at an optimal level.

Lethal hypercapnia during prolonged apnea or bradypnea was terminated by the use of an MO and by insufflation of O_2 into the lungs. In the first case (in apnea) elimination of CO_2 by MO took place without the participation of the lungs, but in the second case it played an essential auxiliary role.

Elimination of CO_2 with VVP of 31.6 ± 3.87-38.8 ± 3.90 ml/min·kg was studied in experiments with AVS and VVS and with completely disconnected breathing. In the course of observation for 3 h after connection of MO the levels of p_aCO_2 and p_vCO_2 under AVS and apneic conditions changed within limits of 48.5 ± 1.58-40.1 ± 3.96 and 58.7 ± 3.53-54.4 ± 3.79 mm Hg, respectively. With VVS and apnea, the corresponding values were 55.9 ± 3.62-49.5 ± 3.80 and 60.0 ± 5.55-54.7 ± 5.31 mm Hg. Under conditions of AVS and bradypnea, VVP was 16.0 ± 3.80 ml/min·kg, and the p_aCO_2 level was maintained between 47.8 ± 0.89 and 46.6 ± 3.17 mm Hg. These results were obtained in the experiments of series I and II when VVP amounted to 25-30% of the minute volume of the circulation (MVC) and when the blood was exposed to MO for 0.9 min. In series III VVP through MO was 13-16% of MVC and the exposure time was 1.2 min.

In all the series of experiments, incidentally, the CO_2 level in the blood was kept stable for 3 h at a somewhat raised value, and showed a tendency to fall toward the end of the experiment. This stability suggests a balance between the processes of CO_2 formation and elimination during operation of MO. That all the animals tolerated the relative hypercapnia satisfactorily under conditions of improved oxygenation of the blood during apnea or bradypnea was shown both by the rapid normalization of the basic parameters of homeostasis after disconnection of MO and transfer of the animals to spontaneous breathing. After only 15-20 min these parameters did not differ significantly from their original values. An improvement to the design of the gas exchanger [2] also led to improvement of the parameters of membrane elimination of CO_2 compared with data obtained previously with the first model of the MO [1, 3].

In the course of the investigation some general rules were established for CO_2 elimination from MO, depending on the intensity of ventilation of MO with gas: if VVP falls below 4 liters/min elimination is significantly reduced, but if VVP rises elimination increases and, according to our results, it reaches the optimal value at 8-10 liters/min. No differences were found in the intensity of CO_2 elimination in the case of ventilation with air or with O_2. The effectiveness of removal of CO_2 from MO is affected by the duration of exposure of the blood in MO: the longer the exposure the more CO_2 is eliminated. The adequacy of CO_2 elimination also depends on the ratio of VVP to MVC.

LITERATURE CITED

1. B. M. Zelikson, L. L. Plotkin, V. I. Shumakov, et al., "A mass-exchange system," Author's Certificate 613758 (USSR), Byull. GKIO, No. 4 (1977).
2. B. M. Zelikson, L. L. Plotkin, B. Ya. Basin, et al., "A mass-exchange system," Author's Certificate 1042753 (USSR), Byull. GKIO, No. 35 (1980).
3. V. I. Skorik, A. I. Levshankov, B. M. Zelikson, et al., Anest. Reanimatol., No. 5, 37 (1981).
4. V. I. Skorik, V. L. Voronel', A. I. Levshankov, et al., Byull. Éksp. Biol. Med., 98, No. 7, 26 (1984).
5. A. F. Andrews, M. D. Klein, J. M. Tomasian, et al., J. Pediat. Surg., 18, No. 4, 339 (1983).
6. R. H. Bartlett, A. F. Andrews, J. M. Toomasian, et al., Surgery, 92, No. 2, 425 (1982).
7. L. Gattinoni, A. Agostoni, A. Pesenti, et al., Lancet, 2, No. 818, 292 (1980).
8. L. Gattinoni, A. Pesenti, A. Pelizzola, et al., Ann. Chir. Gynaec, Fenn., Suppl. 196, 77 (1982).
9. T. Kolobow. L. Gattinoni, T. Tomlinson, and J. E. Pierce, J. Thorac. Cardiovasc. Surg., 75, No. 2, 261 (1978).
10. W. M. Zapol. R. Wilson, C. Hales, et al., J. Am. Med. Assoc., 251, No. 24, 3269 (1984).