GASEOUS EQUILIBRIUM BETWEEN BLOOD AND THE LUMEN OF THE INTESTINE

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Gaseous exchange through the intestinal wall is interesting both theoretically and practically. Even at the beginning of the last century it was shown that oxygen introduced into the intestine is rapidly absorbed [4, 8, 13, and others]. Later it was found that there is then an increased saturation of blood in the portal vein [10] and aorta. Because of the plentiful blood supply to the intestine and the large absorptive surface of the intestinal mucosa, A. Ylppö and co-workers [14, 1] successfully introduced oxygen through the esophagus into the intestine of infants born in an asphyxiated condition. As would be expected, oxygen introduced into the gastrointestinal tract may be used in various conditions associated with an inadequate oxygen supply to the liver [10].

The conditions of gaseous exchange between the blood and the cavity of the intestine have not been sufficiently studied. Long ago, A. Boycott [4] and E. McIver and his co-workers [8] showed that shortly after introducing a mixture of gases into the intestine, the oxygen concentration is quite low.

They supposed that under the influence of diffusion, the oxygen in the intestine comes into equilibrium with that in the blood; however, no comparative measurements were made of the gaseous content of the venous blood from the intestine. Evidently, further study is required, and is reported in the present article.

METHOD

The experiments were carried out on rabbits and cats. A laparotomy was performed under anesthesia induced by 4 ml per kg of 2.5% thiopental sodium injected intravenously. A loop of small intestine was removed from the abdominal cavity, and an incision was made in the wall, which was then carefully washed with warm Ringer's solution. The wall was then isolated from the rest of the intestine by special tourniquets, and 60-40 ml of air or nitrogen was then injected into the intestine through a needle under a pressure not greater than 2-5 cm of water. The intestine was then returned into the cavity, and the wound closed by clips. The body temperature was maintained at 35-36°.

In order to obtain a sample of gas, a certain time later, a portion of the intestinal loop was removed from the cavity and pierced by a thin injection needle connected by flexible rubber tubing to a Haldane blood gas apparatus, where the analysis was made. Blood for analysis was taken from a mesenteric vein of the portion of intestine investigated. Blood gas analysis was made on a van Slyke apparatus. The size of the blood sample was 0.2 ml. Analyses were also made of alveolar air obtained through a tracheal cannula connected by a thin rubber tube to the Haldane apparatus. Alveolar air was sucked into the apparatus by rapidly lowering the mercury reservoir at the end of an inspiration. In all, 30 rabbits and 4 cats were used.

RESULTS

One hour after injecting air into the intestine, the amount of CO_2 in the lumen was 5-7.5%, and was approximately equal to the CO_2 concentration in the alveolar air (Table 1).

Only a very small amount of oxygen remained in the intestine. Two to four hours after injecting air into the intestine, only 0.5-2.3% of oxygen remained, corresponding to a pressure of 3.5-18 mm of mercury. When other conditions were left unchanged and the intestinal loop was filled with pure nitrogen (obtained from air by absorbing oxygen in a Haldane apparatus), then after $\frac{1}{2}$-2 hours the amount of oxygen in the intestinal lumen had again reached 0.5-2.3%. Thus, oxygen is not only absorbed, but under certain conditions it is also able to pass into the intestine from the blood. It must be noted that the tension of oxygen in the intestinal lumen is very low, which may be due to the low oxygen tension in venous blood leaving this part of the intestine. However, the oxygen tension in the mesenteric veins was very much higher, and according to our measurements had a value of 20-50 mm of mercury (Table 2).

TABLE 1. Results of Experiment on April 20, 1957

Time of collection of sample	Composition of gas from intestine (%)		Composition of alveolar air (%)	
	O_2	CO_2	O_2	CO_2
Air injected into intestine at 10:37 a.m.	—	—	—	—
11 : 37 a.m.	10,1	7,6	9,8	6,6
12 » 37 »	7,8	5,8	10,8	6,2
13 » 37 »	3,0	5,0	12,6	5,4
14 » 55 »	2,0	5,4	13,5	5,0

TABLE 2. Oxygen Tension in the Lumen of Intestine and in Mesenteric Veins

Number of experiment	Oxygen in mesenteric veins			Oxygen in lumen of intestine after steady state had been reached (after 2-4 hrs)	
	In volume %	Saturation (%)	Tension in mm mercury over pH range 7.2–7.6	Amount (in %)	Tension (in mm mercury)
Rabbits					
1	—	—	—	1,9	15
2	—	—	—	1,5	10
3	—	—	—	0,7	5,5
4	—	—	—	2,3	18
5	—	—	—	2,2	17
6	—	—	—	1,1	9
7	—	—	—	0,5	4
8	16,1	84	41—64	2,7	20,5
9	16,2	84	41—64	1,1	9
10	13,8	74	34—54	0,5	4
11	15,2	80	38—58	2,1	16
12	8,3	43	23—35	1,3	10
13	12,3	73	34—52	1,4	11
14	13,5	71	32—51	1,6	12,5
15	11,9	63	29—45	0,7	5,5
16	14,4	75	35—55	1,4	11
17	16,0	84	41—64	0,7	5,5
Cats					
1	15,1	71	39—60	1,4	11
2	16,3	75	41—65	0,4	3
3	16,2	74	40—64	0,3	2,5
4	—	—	—	0,4	3

The oxygen tension in the blood over a certain range of variation of pH was calculated from the oxyhemoglobin dissociation curve for cats and rabbits as given by G. Bartels and H. Harms [2]. To calculate the percentage circulation of oxygen, the volume in the blood was measured by a van Slyke apparatus.

In control experiments, 300-400 ml of pure nitrogen was introduced into the abdominal cavity of an intact rabbit. After 2-3 hours the oxygen concentration had reached a steady level of 6-7.5%, corresponding to 50-57 mm mercury.

It is known that when gas is introduced into the serous (abdominal or pleural) cavities, or else injected subcutaneously, gaseous equilibrium is attained very rapidly. Then, the oxygen tension in the serous cavity or subcutaneous vesicle becomes equal to the venous tension [6, 9, 11 and others]. As our experiments have shown, the diffusion of CO_2 into the intestinal cavity occurs as quickly and as completely as into other body cavities, but the oxygen tension remains low. It is important to note that the oxygen tension in the venous blood from the intestine is 15-35 mm mercury, and is always greater than the tension in the intestinal lumen. To explain the effect, it must be remembered that in the intestine there are well-developed arteriovenous anastomoses, as a result of which a proportion of the arterial blood passes directly into the veins. The oxygen tension in such mixed blood will naturally be higher than in the tissues. However, were the difference between the oxygen tensions in the lumen and the veins due only to these anastomoses, then the value of the oxygen tension in the intestinal tissue would be extremely low, having a value of 10, 5, or even of 3 mm mercury. It is difficult to believe that this is so, because of the relatively high metabolic rate in the intestine, and from the calculated values of the minimum oxygen tension in the capillaries required for respiration [5, 12].

Evidently, as far as oxygen is concerned, there are certain special conditions in the intestine which differ from those in the serous cavities and in the tissues themselves (as affecting, for example, a mixture of gases injected into the subcutaneous tissue). We may suppose that in the cavity of the small intestine there is always a very low oxygen concentration despite the abundant blood supply. Further evidence of the almost anaerobic conditions in the intestine is that intestinal mammalian and human parasites are typical anaerobic organisms [3].

SUMMARY

A study was made of the gaseous exchange between the cavity of the small intestine and the blood flowing from it in the mesenteric veins. The gaseous composition of the blood in the mesenteric veins was examined after air or nitrogen introduced into the intestine had reached a constant composition. The oxygen tension in the venous blood was always 15-35 mm Hg higher than that in the intestinal lumen. The oxygen tension in the intestine remained very low despite the abundant blood supply.

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