EFFECT OF LOCAL DISTURBANCE OF BRONCHIAL PATENCY ON THE CIRCULATION AND GAS EXCHANGE IN THE LUNGS

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Alveolar hypoxia is regarded as a leading pathogenetic factor in pulmonary hypertension in patients with chronic obstructive bronchitis [1, 2, 4, 5]. However, in most cases this view is not based on reliable factual evidence of the effect of disturbance of bronchial patency of the alveolar ventilation and composition of the alveolar gas on pulmonary hemodynamics and gas exchange.

The aim of this investigation was to obtain proof that alveolar hypoxia develops in the presence of local bronchial obstruction and to establish the role of the latter in disturbances of the pulmonary circulation and gas exchange.

EXPERIMENTAL METHOD

Two series of experiments were conducted on male mongrel dogs weighing 13-15 kg. In series I (nine dogs) thoracotomy was performed in the 5th left intercostal space under general anesthesia (fluothane) with artificial ventilation of the lungs. The bronchus and artery of the diaphragmatic lobe of the left lung and the thoracic portion of the aorta were

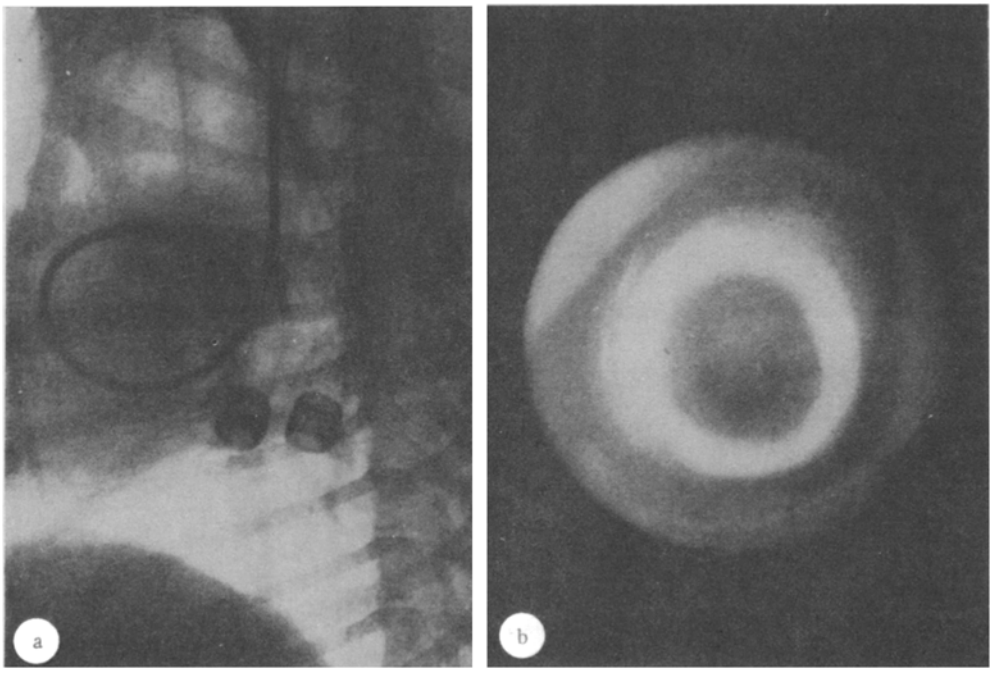

Fig. 1. Lateral roentgenogram of dog's chest (a) and endophotograph of lobar bronchus (b). Cylinders located in both diaphragmatic bronchi and catheters in pulmonary artery and aorta can be seen in the roentgenogram. The endophotograph demonstrates the position of the cylinder relative to the bronchial walls.

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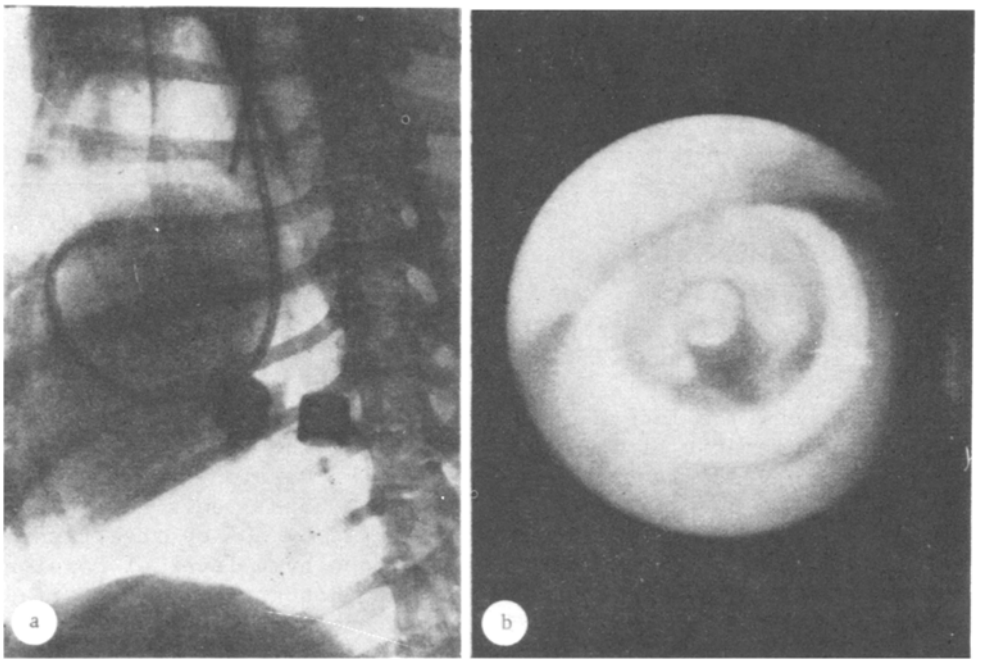

Fig. 2. Lateral roentgenogram of dog's chest (a) and endophotograph of lobar bronchus (b). Both cylinders can be seen on the roentgenogram, the tube inside the lumen of one of them. The endophotograph shows a cylinder with a tube inside it (the space between the tube and the wall of the cylinder is filled with Porolon).

isolated. A catheter was introduced in the retrograde direction through one of the segmental bronchi of the diaphragmatic lobe in order to sample the alveolar gas. The cuff transducers of an electromagnetic flowmeter were applied to the lobar artery and descending aorta. Two rubber tubes were passed through the rima glottidis and a tracheostomy. The lumen of one tube opened 2-3 cm above the bifurcation of the trachea, while the second tube was passed into the diaphragmatic bronchus and was fixed to it by two ligatures. The thoracic wound was closed without drainage and the catheters were brought out onto the surface of the chest. After the dogs had begun to breathe spontaneously again, the superficial anesthesia was maintained by intravenous injection of hexobarbital. After 15-20 min, when values of the respiration and pulse rates had stabilized, the initial values of the respiratory minute volume of the left diaphragmatic lobe and of the remainder of the lungs (total ventilation), the partial pressure of oxygen (pO_2) in the alveolar gas in that lobe, and the blood flow in the aorta and lobar artery were measured. The measurements were repeated after constriction of the proximal end of the tube inserted into the lobar bronchus, at first by 30% and later by 80%. The ventilation of the lungs and lobe was determined by means of an air flowmeter. At the end of the experiment the thorax was reopened and the position of the catheters and transducers was determined. In series II (six dogs) the effect of bronchial obstruction on the pulmonary hemodynamics and gas exchange was studied in chronic experiments. Under general anesthesia (hexobarbital, 25 mg/kg) the right jugular vein and superior thyroid artery were isolated, and catheters passed through them into the pulmonary artery and descending aorta. The proximal ends of the catheters were tied to the posterior surface of the animal's neck. On the same day outline bronchography with tantalum was carried out to determine the diameters of the diaphragmatic bronchi. In the course of 5 days the dogs became accustomed to the experimental situation, to wearing a mask, and to the tube introduced into the esophagus. On the 6th day the initial values of pressure in the pulmonary artery and aorta were measured in the conscious dogs (the pressure transducer was applied at the level of projection of the apex beat), blood samples were taken, the pneumotachogram and transpulmonary pressure recorded. The air flow in the mouth was measured by means of a Fleisch tube, fitted into the mask. Fluctuations of intrathoracic pressure were recorded by means of a tube introduced into the lower third of the esophagus. The total work of respiration and the bronchial resistance at inspiration and expiration were calculated without destruction of the respiratory loop [3]. After measurement of the initial values, under general anesthesia an elastic rubber cylinder, surrounded by a thin layer of Porolon, was introduced through a bronchoscope into the

TABLE 1. Ventilation, pO_2 in Alveolar Gas, and Ratio of Blood Flow along Lobar Artery to Total Blood Flow ($\dot{Q}_{lob}/\dot{Q}$) in Dogs after Disturbance of Patency of Lobar Bronchus (M ± m, n = 9)

Parameter	Before narrowing of tube	Degree of constriction of tube, %	
		30	80
Respiratory minute volume, liters/min	9,5±0,7	12,4±1,2	13,8±1,4*
Ventilation of lobe	0,9±0,04	1,2±0,1*	0,5±0,06*
pO_2 in alveolar gas of lobe, mm Hg	107,6±1,8	94,0±2,4*	73,4±2,1*
$\dot{Q}_{lob}/\dot{Q}$, %	21,5±1,1	20,4±1,2	18,2±0,9*

Legend. Asterisk indicates significant differences from values before constriction of tube ($P < 0.05$).

left diaphragmatic bronchus. The length of the cylinder was 10 mm and its internal diameter was 25-30% less than the diameter of the lobar bronchus. The cylinder was fixed in the lumen of the bronchus due to the viscoelastic properties of the Porolon. A second cylinder was introduced into the lumen of the right diaphragmatic bronchus 3 days later, by the same method (Fig. 1). The left lobar bronchus was constricted by 80% by insertion of an x-ray contrasting tube 2 mm in diameter and 10 mm long, surrounded by a layer of Porolon, into the lumen of the cylinder (Fig. 2). Roentgenography and endophotography were carried out on the anesthetized dogs. The parameters were recorded without anesthesia on the 3rd day after insertion of the 1st and 2nd cylinders, and on the 3rd day after constriction of the left diaphragmatic bronchus. Next, the intrapulmonary distribution of the blood flow was studied in five dogs. For this purpose albumin microspheres labeled with ^{99m}Tc were injected intravenously. The dogs were killed 5 min after injection of the indicator by means of large doses of hexabarbital. The lungs were removed from the thorax and investigated in a gamma-camera. Accumulation of indicator in the lobes was estimated as a percentage of the total injected dose. The control group consisted of five healthy dogs of the same weight.

EXPERIMENTAL RESULTS

Constriction of the lumen of the tube introduced into the diaphragmatic bronchus by 30% was accompanied by an increase of 31% in the total ventilation of the lungs and by 33% in the ventilation of the lobe (Table 1). Despite this fact, pO_2 in the alveolar gas in the lobe fell on average by 14 mm Hg. More marked hypoxia developed after constriction of the tube by 80%. Against the background of a further increase in the total respiratory minute volume (RMV) ventilation of the lobe decreased to 0.5 liter/min, whereas pO_2 in the alveolar gas decreased by 34.2 mm Hg compared with initially. Evidently two factors were decisive for the development of alveolar hypoxia in this case — the degree of constriction and the anatomical dead space formed by the tube. Measurements of the blood flow in the lobar artery and aorta showed that the development of local alveolar hypoxia was accompanied by reduction of perfusion of the lobe relative to the unchanged cardiac output (Table 1). This ratio of local to total blood flow indicates the possibility of an intrapulmonary redistribution of perfusion between the lobes of the lungs and the compensatory character of this response.

In the experiments of series II chronic bronchial obstruction was created. Analysis of the results (Table 2) shows that after insertion of the cylinder into one bronchus no appreciable changes took place in the work done, RMV, or the parameters of the hemodynamics and gas exchange. Additional narrowing of the lumen of the second diaphragmatic bronchus caused, first, an increase in bronchial resistance to expiration by 35% compared with initially. RMV and the respiration rate were increased by 24 and 65%, respectively. The creation of bilateral obstruction was accompanied by an increase, though not significant, in the systolic pressure in the pulmonary artery and a decrease in the partial pressure of oxygen in the arterial blood (p_aO_2). It can be tentatively suggested that the increase in vascular resistance of the lungs and arterial hypoxemia was due to summation of the effects of hypoxic vasoconstriction and the venous shunt of blood in each diaphragmatic lobe.

More marked changes in ventilation and the circulation took place after constriction of the lumen of one diaphragmatic bronchus by 80%. The total work of respiration and the bronchial resistance at inspiration and expiration were increased by 160, 42, and 81%, respectively, compared with the previous values. RMV was increased by 62%. Changes in the hemodynamics were characterized by an increase in systolic pressure in the pulmonary artery on average to 35.3 mm Hg. The systolic pressure in the aorta at these times of observation was

TABLE 2. Parameters of Mechanics of Respiration, Hemodynamics, and Gas Exchange in Dogs after Creation of Bronchial Obstruction (M ± m, n = 6)

Parameter	Initial state	Stage of experiment		
		I	II	III
Total work of respiration, kg/min	0,225±0,015	0,235±0,043	0,258±0,051	0,671±0,096*
Bronchial resistance, $\frac{\text{cm water}}{\text{liters/sec}}$:				
inspiration	1,1±0,3	1,8±0,1	1,9±0,3	2,7±0,5*
expiration	3,1±0,2	3,9±0,5	4,2±0,6	7,6±1,8*
RMV, liters/min	8,3±0,9	9,6±1,2	10,3±0,5*	16,7±1,8*
Respiration rate, min^{-1}	20,0±1,5	26,0±1,3	33,0±1,8*	44,0±1,9*
Systolic pressure in pulmonary artery, mm Hg	26,4±0,6	27,3±1,2	29,1±0,8	35,3±0,9*
Systolic pressure in aorta, mm Hg	135,0±3,1	127,4±4,0	138,1±8,1	133,4±4,5
p_aO_2, mm Hg	86,5±1,3	85,1±1,2	82,9±1,8	73,4±2,1*

Legend. I) Cylinder in one diaphragmatic bronchus, II) cylinders in both diaphragmatic bronchi, III) after insertion of tube into one cylinder. Asterisk indicates significant differences compared with values in initial state ($P < 0.05$).

TABLE 3. Distribution of Albumin Microspheres, Labeled with ^{99m}Tc, in Lungs of Normal Dogs and after Creation of Bronchial Obstruction (in % of total quantity of indicator injected, M ± m)

Experimental conditions	Left lung		Right lung	
	diaphragmatic lobe	apical and cardiac lobes	diaphragmatic lobe	apical and cardiac lobes
Control (n = 5)	29,7±0,8	14,6±0,6	33,9±0,9	21,8±0,6
Unilateral obstruction (n =5)	13,9±1,4*	16,7±1,6	43,1±1,9*	26,2±1,6*

Legend. Asterisk indicates significant differences compared with values in normal dogs ($P < 0.05$).

the same as initially. A significant disturbance of the gas exchange function of the lungs was discovered, with a reduction of p_aO_2 to 73.4 mm Hg.

The time course of the ratio of the lobar blood flow to the cardiac output, noted in the experiments of series I, is evidence that a local increase of vascular resistance, due to hypoxic vasoconstriction, can be compensated by an intrapulmonary redistribution of perfusion. This fact was confirmed by the distribution of the radioactive indicator in the dog's blood. After constriction of the lobar bronchus by 80% perfusion of the left diaphragmatic lobe was reduced by 53.5% compared with the control (Table 3). In the remaining zones of the lungs the blood flow was increased, more especially (by 27%) in the right diaphragmatic lobe.

A disturbance of bronchial patency thus leads to the development of alveolar hypoxia, the severity of which depends on the degree of constriction of the bronchial lumen. Local alveolar hypoxia is one of the leading causes of a local increase of vascular resistance. A rise of pressure in the pulmonary artery is due to an increase in the number of vascular zones in which hypoxic vasoconstriction arises, and is maintained throughout the period of obstruction. The degree of increase of pressure is determined by the irregularity and depth of the alveolar hypoxia and the intensity of intrapulmonary compensatory reactions, in the form of a redistribution of the blood flow between the lobes of the lungs. Perfusion of unventilated regions is accompanied by the formation of a venus shunt of blood, the magnitude of which largely determines the decrease in p_aO_2.

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