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ISCHEMIC AND POSTISCHEMIC DISTURBANCES OF THE PULMONARY MICROCIRCULATION

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Temporary ischemia of the lung leads to functional disturbances in the pulmonary circulation [2, 7]. Considering that the microcirculation of any organ is a vital factor providing for its nutrition and function [4, 9-12], it was decided to study the pulmonary microcirculation during and after various periods of ischemia of the lung.

EXPERIMENTAL METHOD

In 40 experiments on five groups of dogs (eight animals in each group) and under combined anesthesia and artifical ventilation of the lungs with a mixture of air and oxygen, left-sided thoracotomy was performed and the pulmonary artery, the main bronchus, and pulmonary veins of the left lung were isolated. Ischemia was induced by successive application of atraumatic clamps to all structures in the root of the left lung for 30, 60, 90, 120, and 180 min in each group, respectively. The main bronchus was clamped at the height of expiration. The pulmonary microcirculation was studied by means of the LYUMAN K-1 biological contact microscope, mounted on the stand of an MLK-1 microscope [3]. The dark field method of investigation was used. Observations were made and photographs taken with contact 10 × 0.30 and 20 × 0.75 epiobjectives and an MFN-12 photomicrographic attachment. The contact objective was moved up to the lung until it touched the visceral pleura. To prevent movement of the region examined relative to the objective a vacuum fixer fitted to the contact objective was used. Observations were made after thoracotomy, during temporary exclusion of the lung from the circulation and ventilation, and during the 30 min after ischemia. The pressure in the pulmonary trunk was recorded at the same time by direct manometry and the cardiac output was determined by the thermodilution method.

EXPERIMENTAL RESULTS

On biomicroscopy of the normal lung the alveoli appeared as round or oval structures with thin and even walls and they were clearly separated from one another by interalveolar spaces. A many-looped network of capillaries could be seen against the background of the alveoli. Along the outer borders of the capillaries and interalveolar spaces there was a band of increased illumination because of reflection of light from their walls (Fig. 1). Arterial and venous microvessels of the interalveolar spaces differed in the direction of the blood flow at points where the microvessels divided or joined together. Blood cells in the stream occupied a central axial postion; a paler, thin layer of plasma could be identified near the walls of the vessels.

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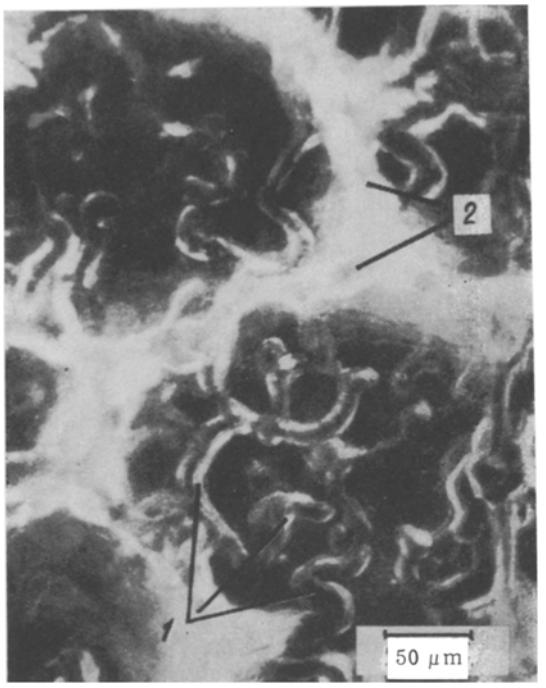

Fig. 1. Normal lung. 1) Network of capillaries with clear outlines against the background of an alveolus; 2) interalveolar spaces with microvessels; 30 ×.

Stasis of the blood developed quickly in the microvessels of the lung after clamping of all structures of its root. After 15-30 min the erythrocytes were grouped in "rouleaux," but during the first hour of ischemia no significant disturbances of the microstructure of the lung could be detected. Later deaeration appeared in the lung, intravascular aggregation of blood cells intensified, and aggregates of large granules and areas of vessels containing mainly plasma or only blood cells were formed. Zones with indistinct outlines of the pulmonary vascular pattern and complete absence of aeration appeared. The disturbances of the microstructure of the lung were clearly visible after only 2 h of ischemia and progressed during the third hour of exclusion of the lung from the circulation and ventilation (Fig. 2a, b).

After the end of ischemia restoration of the microcirculation in the lung varied depending on the duration of previous ischemia.

Restoration of the blood flow and ventilation to the lungs after 30 min of ischemia was followed by rapid recovery of the blood flow in all microvessels. The microcirculatory pattern corresponded to the original state.

After 60 min of ischemia the circulation was restored practically immediately in most zones of the lung examined. However, in single capillaries blood stasis remained, and in most functioning capillaries the blood flow was moderately slowed. In the course of observation a tendency was noted for the velocity of the blood flow to return to normal, for moderate overfilling of the microvessels with blood, and for widening of the interalveolar spaces (Fig. 3a).

Immediately after the end of ischemia lasting 90 min the circulation was restored only along the large vessels. By the 7th-10th min of the post-ischemic period, simultaneously with restoration of the blood flow along the capillaries, rapid overfilling of the microcirculatory system with blood was observed, with signs of intravascular aggregation of blood cells, tortuosity of the capillaries, deformation of the alveoli, and a reduction in the lung.

After ischemia for 120-180 min recovery of the circulation in the lung was accompanied by the development of marked disturbances of the microcirculation. These took the form of considerable slowing of the corpuscular velocity of the blood flow, massive overfilling of the alveolar vascular network with blood, signs of intravascular aggregation and stasis, and

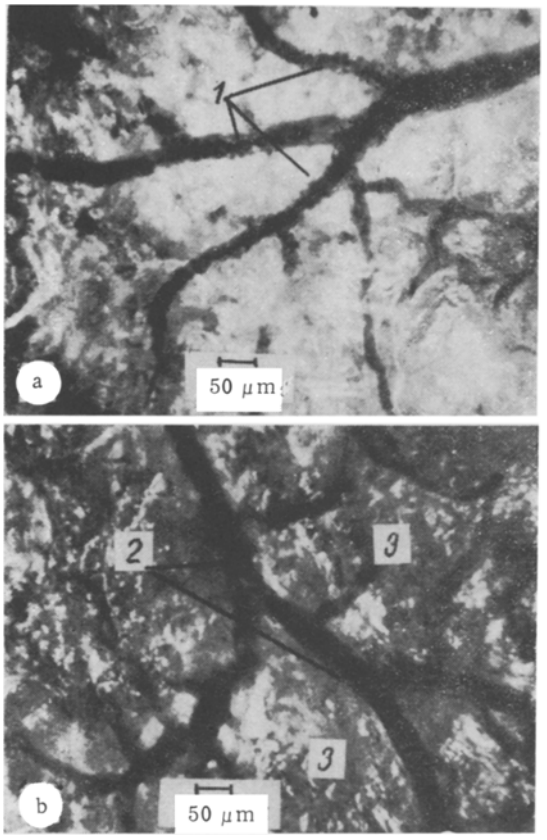

Fig. 2

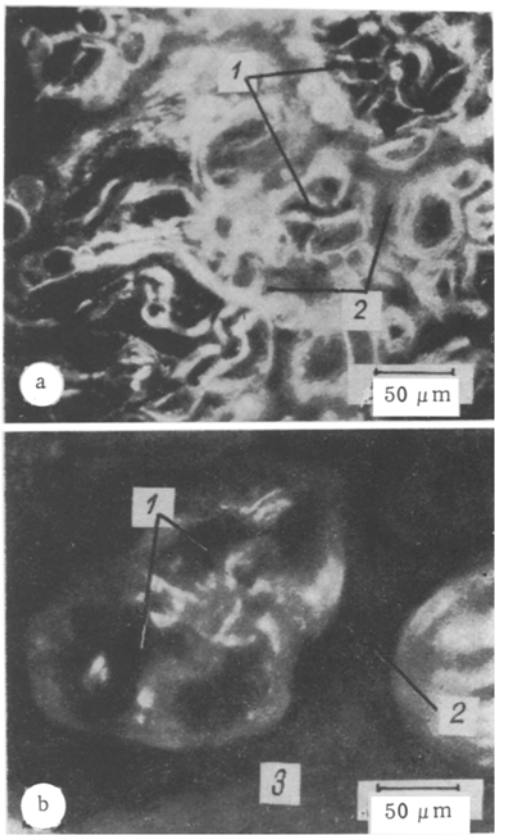

Fig. 3

Fig. 2. Lung during ischemia. a) After 60 min; aggregation of blood cells (1) can be seen against the background of the intact microstructure of the lung tissues; b) after 120 min; blurring of outlines of vascular pattern (2), deaeration of lung tissue (3); 70 ×.

Fig. 3. Lung after ischemia. a) After 60 min: stasis of blood in individual capillaries (1), widening of interalveolar spaces (2); b) after 180 min; blurring of outlines of capillaries, stasis of blood (1), marked widening of interalveolar spaces (2), hemorrhagic edema (3); 140 ×.

the presence of regions in which the circulation was not restored. In the course of repeated observations the hemorrhagic background increased and zones appeared with blurred outlines of the vascular pattern and foci of alveolar edema and hemorrhage (Fig. 3b).

In spite of the great powers of adaptation of the cardiopulmonary apparatus, microcirculatory disturbances in on e lung after long periods of ischemia (120-180 min) were accompanied by changes in the hemodynamic parameters in the pulmonary circulation. In these groups of experiments the volume blood flow was reduced by 15.3 and 23% of its initial value, respectively ($P < 0.001$) and the total pulmonary vascular resistance was increased by 20-3% ($P < 0.01$).

A definite relationship was thus established between the duration of ischemia and the appearance, spread, and intensity of the intravascular and vascular pathological changes in the lung both during ischemia and in the early postischemic period. The intravascular postischemic changes consisted mainly of slowing of the corpuscular velocity of the blood flow, aggregation of blood cells, and stasis of blood in the microvessels; the vascular changes consisted of a change in the form and capacity of the microcirculatory system and pathologically increased permeability of the walls of the microvessels. According to data in the literature and the results of the present experiments, the postischemic disturbances described above may be due to several causes: stasis of blood during ischemia, which can stimulate increased secretion of thrombogenic substances [5, 6], ischemic edema of the capillary endotheliocytes with the formation of cytoplasmic outgrowths that constrict or occlude the

lumen of the capillaries [8], and the accumulation in increased concentrations of vasoactive hormones (histamine, acetylcholine, kinins), facilitating the development of pathologically increased permeability of the microvessel walls [1].

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