CHANGES IN FUNCTION AND STRUCTURAL ADAPTATION OF THE HEART AND LUNGS IN DISTURBANCES OF THE CORONARY AND PULMONARY CIRCULATION

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In chronic experiments on dogs using roentgenoangiographic, macroscopic, and microscopic methods, changes in the coronary, pulmonary, and bronchial arteries were studied after ligation of the descending branch of the left coronary artery or the left pulmonary artery. In the early periods after ligation of the arteries, intervascular anastomoses are insufficient for restoring the disturbed circulation. ECG changes characteristic of antero-apical infarcts thereupon arise. As a result of disturbance of the external respiratory function, hypoxic hypoxia and various other disorders develop. By the 14th-35th day, as a collateral circulation develops in the heart and lungs, the indicies of cardiopulmonary function return toward their initial value.

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Structural changes in the numerous arteries of the heart and lungs during a disturbance of the circulation in these organs have received comparatively little study [1, 3, 5]. However, dynamics of the indices of function alone are insufficient for assessment of the plasticity of the collateral circulation [2,4,7].

In the present investigation, structural changes in the arterial system of the heart and lungs were compared with physiological indices during adaptation to disturbance of the coronary and pulmonary circulation.

EXPERIMENTAL METHOD

Experiments were carried out on 76 dogs. In 6 animals for control purposes thoracotomy was performed without subsequent ligation of vessels, while in the rest the coronary or pulmonary arteries were ligated. Biochemical and physiological indices were determined in the usual way. At various times (from a few hours to 412 days) the animals were sacrificed, a thin suspension of red lead was injected into the system of the coronary, pulmonary, or bronchial arteries, and these vessels were studied by roentgenoangiography, stereoroentgenography, and by macroscopic and microscopic methods.

EXPERIMENTAL RESULTS

In the first 48 h after ligation of the descending branch of the left coronary artery the contrast material filled only a few peripheral vessels connected by frequent anastomoses. Only traces of contrast material penetrated, however, into the main trunk below the ligature (Fig. 1A). The distal segment of the ligated vessel was well filled with the same material 8-15 days later, because of the development of arterial anastomoses between branches of the right and left coronary arteries and of an increase in their diameter (to 0.4-0.6 mm). Later still, considerable reorganization of the vascular system of the heart took place. Large anastomoses were formed at some distance from the point of ligation, connecting distal ramifications of neighboring coronary branches (Fig. 1B). In the zone of the myocardial infarct, despite the development of a network of blood vessels, as a rule marked degenerative and necrotic changes were observed.

In all the experimental animals for a period of 2-3 weeks changes were found in the ECG characteristic of antero-apical myocardial infarct (lowering of the voltage or inversion of the T wave, widening of the Q-T intervals and QRS complex, appearance of a deep Q_I wave, displacement of the S-T segment) (Fig. 1C).

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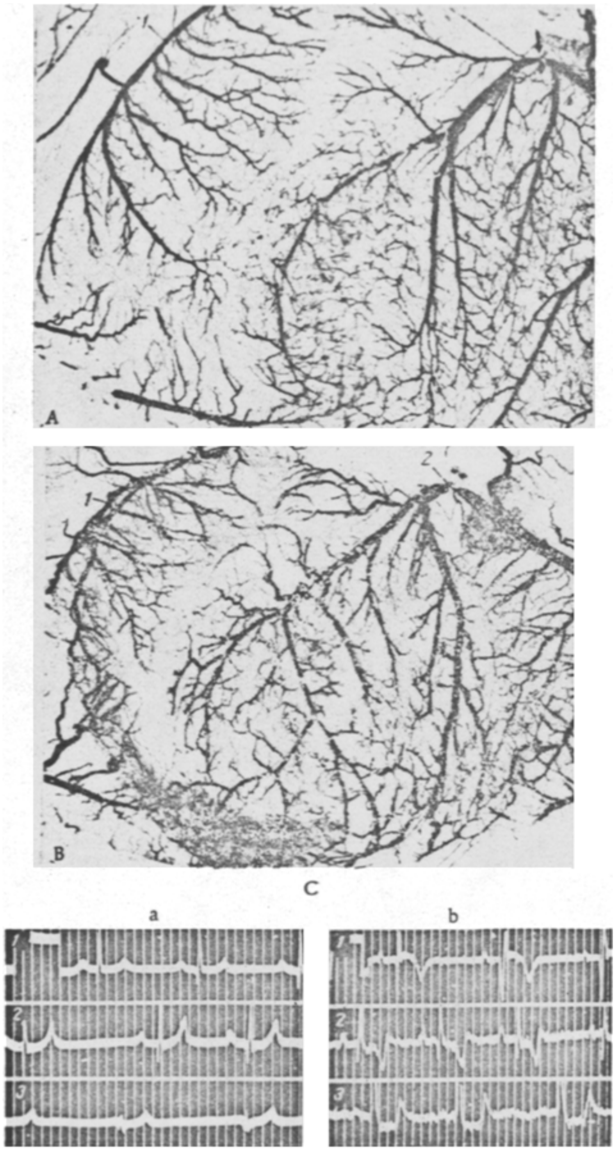

Fig. 1. Arterial system of dog's heart 28 h (A) and 410 days (B), and ECG (C) under normal conditions (a) and 3 days (b) after formation of a myocardial infarct. 1) right; 2) left coronary artery; X denotes point of ligation, arrows indicate dilated anastomoses between neighboring branches. Leads are shown on ECG by numbers.

In the first 3–4 days after development of myocardial infarction the total glutathione concentration (and also the total oxidized and reduced glutathione) in the blood of the animals fell from 29 ± 0.7 to 17 ± 0.3 mg % ($P < 0.001$). By the 10th day after the operation the glutathione concentration had risen to 60 ± 2 mg %, and by the 27th-28th day it was close to its preoperative level.

On the 3rd day after the operation a considerable decrease in the blood protein concentration was found in all experimental dogs (3.97 ± 0.45%; normal 7.06 ± 0.3%; $P < 0.01$), mainly on account of the albumins (1.11 ± 0.5%; normal 4.19 ± 0.3%; $P < 0.001$). By the 30th day the content of total protein and albumins had returned to its initial level. The blood nonprotein nitrogen was increased by about 2-2.5 times after disturbance of the coronary circulation (from 24.9 ± 1.1 to 49.6 mg %; $P < 0.001$), and the fibrinogen concentration was increased by 4-4.5 times (from 277 ± 11.3 to 1010 ± 12.5 mg %; $P < 0.001$).

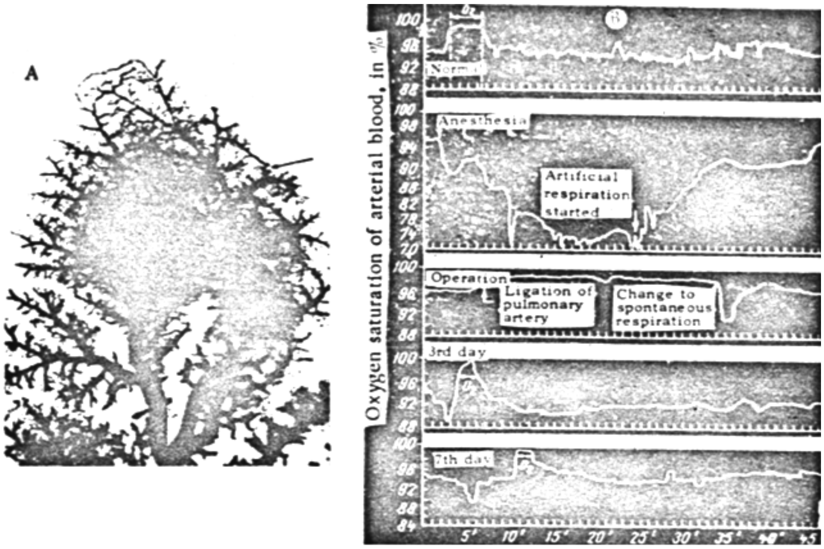

Fig. 2. Vascular system of the lungs (A) and dynamics of blood oxygen saturation (B) after disturbance of circulation in pulmonary artery. Newly formed arterial arcades can be seen in A (arrow) in the right apical lobe of the lung of dog No. 73, 169 days after ligation of the anterior segmental artery. Twice normal size.

The Takata-Ara reaction, which is normally negative, was positive in all the animals for 25-30 days. Significant changes in carbohydrate and lipid metabolism also were observed. In particular, the blood sugar of the dogs rose from 93 ± 7 to 156 ± 9% ($P < 0.001$), returning to normal in the 4th or 5th week. The blood cholesterol was also increased, from 120-160 to 190-200 mg %.

The arterial system of the lungs is less plastic than that of the heart and does not adapt itself so quickly to circulatory disturbances in the organ. In the first 7-14 days after ligation of one or several segmental branches the main trunks and their ramifications usually were filled to an even lesser degree than in the heart with contrast material. Opening of anastomoses and an increase in their diameter took place gradually, but even on the 52nd-69th day, it was not always possible to see good filling of the ligated vessels. After 144-169 days, large anastomoses began to form at a distance from the point of ligation (Fig. 2A), compensating for the disturbed blood flow. More considerable changes after disturbance of the blood flow in the lungs were observed in the bronchial arteries soon after the operation. In the first 3-7 days the pattern of the bronchial arteries in the zone of exclusion became more intensive. When the material was injected into the bronchial arterial system, it passed along the anastomoses to fill many peripheral branches of the pulmonary artery also. With the course of time the branches of the pulmonary arteries became progressively wider in diameter and more tortuous, and the contrast material injected into them penetrated into all branches of the pulmonary artery in the excluded and even the intact segments.

The changes in external respiration after ligation of branches of the pulmonary artery were ill defined. They were more marked after ligation of the main trunk, when the respiration rate increased from 12-22 to 54-68 per minute. The amplitude of the respiratory movements was reduced by 50-75% below the initial level. The minute volume of respiration increased from 1.7-3.2 to 3.8-4.2 liters. A study of the oxyhemograms revealed only a transient increase in the percentage saturation of the arterial blood with oxygen, which was associated with an increase in ventilation of the lungs [6] and redistribution of the blood. By the 3rd day the oxygen saturation of the blood had fallen to 89-91%, but by the 7th-14th day it had reached its initial level again (Fig. 2B). Investigation of the composition of the blood gases in these animals by Van Slyke's method showed that in the early postoperative period a state of hypoxic hypoxia was present. The oxygen concentration in the arterial blood fell to between 16.8 ± 3 and 17.8 ± 3.2 vol.%; $P < 0.01$ (normal 17-18 vol.%), and in the venous blood to between 11.4 ± 2.1 and 12.2 ± 2.4 vol.%; $P < 0.02$ (normal 14-15 vol.%). The oxyhemoglobin dissociation curve was displaced upward and to the left compared with normal.

Hence, in the initial period after experimental ligation of both the coronary and pulmonary arteries, the existing anastomoses are insufficient both physiologically and anatomically to enable rapid recovery of the disturbed blood flow to take place. Complex physiological disturbances develop in the animals. Later, during development of the collateral circulation and operation of adaptive mechanisms, the previously observed changes diminish in intensity.

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