CORRELATION BETWEEN CARDIODYNAMICS AND PULMONARY GAS EXCHANGE IN EXPERIMENTAL ACUTE RESPIRATORY INSUFFICIENCY

G. G. Rogatskii

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KEY WORDS: cardiodynamics; respiratory insufficiency; gas exchange.

Relations between the circulation and respiration in acute progressive respiratory insufficiency have received little study. In particular, the dynamics of changes in parameters of the pumping and contractile functions of the myocardium in acute arterial hypoxemia has been discussed. Besides evidence of stability of cardiac output [4, 8] and myocardial contractility [1, 9] parameters, there have been other reports also of their worsening [3, 5, 7, 13]. According to Meerson [2], changes in the contractile properties of the myocardium during hypoxemia develop in definite stages.

To determine the character of cardiorespiratory relations, changes in parameters of the cardiodynamics and pulmonary gas exchange were studied in dogs in which a syndrome of acute respiratory insufficiency (ARI) was produced experimentally.

EXPERIMENTAL METHOD

Thirty dogs weighing 10-19 kg were injured under intravenous hexobarbital anesthesia (3-4 mg/kg) either by dislocation of a previously prepared fragment of the chest wall (in 12 animals) or by contusion of the right lung by means of a falling metal plate (in 18 animals). The right ventricle was catheterized through cannulas implanted into the jugular vein and external carotid artery, by means of a microcatheter, and a thermistor probe was introduced into the aortic arch. As a result of these procedures the following investigations could be carried out before and 1, 2, and 4 h after trauma, and also once in the course of the next 7 days: recording the cardiac index (CI) and stroke index (SI) by the thermodilution method, measuring maximal systolic (MSP) and end-diastolic pressure (EDP) in the right ventricle (electromanometrically), and taking arterial blood samples for measurement of the partial pressure of CO_2 (p_aCO_2) and O_2, during inhalation of air (p_aO_2) and also during inhalation of 100% O_2 for 15 min (P_aO_2) by the micro-Astrup method. During inhalation of 100% O_2, incidentally the value of P_aO_2 was about 5 times higher than during inhalation of room air. The results were subjected to statistical analysis.

EXPERIMENTAL RESULTS

Of the 30 animals 18 survived the early post-traumatic period satisfactorily, but 12 dogs died between 3 h and 7 days after trauma. Analysis of the data obtained on animals which died revealed four stages of the process, differing in the rate and direction of changes in the cardiac output parameters. The duration of the stages was 30 min, 4-24 h, 1-6 days, and 4 h to 2 days respectively, for stages I, II, III, and IV.

It will be clear from Table 1, the data in which illustrate dynamics of the parameters recorded in the course of the process, trauma caused a definite cardiodynamic reaction in stage I, manifested as a significant decrease in SI ($P < 0.005$), and a tendency for CI to decrease and MSP and EDP to increase. After these parameters returned partly to normal in stage II, a fresh tendency for SI to decrease was again observed (while CI remained the same), and there was a marked increase in EDP. In the terminal stage IV, because of these tendencies a significant decrease was observed in SI (on average by more than 25% of the original value), with a maximal increase in EDP, which continued to progress until death ($P < 0.001$), and a significant increase in MSP ($P < 0.01$).

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TABLE 1. Cardiodynamics and Arterial Blood Gas Composition in Dogs during ARI Induced by Contusion of the Lung and Chest Injury (M ± m, n = 12)

Stage of post-traumatic process	CI, ml/kg·min	SI, ml/kg	MSP, mm Hg	EDP, mm Hg	P_aCO_2, mm Hg	P_aO_2, mm Hg	P_aO_2, mm Hg
Initial	137±11,79	1,13±0,9	20,6±1,12	1,12±0,40	34±1,87	82±1,77	430±4,81
I	101±6,46	0,64±0,07	25,6±3,27	3,08±1,28	32±2,30	80±3,65	420±17,47
P	<0,05	<0,005	>0,05	>0,05	>0,05	>0,05	>0,05
II	148±11,20	0,98±0,08	24,3±1,83	2,10±0,70	33±1,91	86±4,31	378±8,14
P	>0,05	>0,05	>0,05	>0,05	>0,05	>0,05	<0,05
III	141±7,76	0,87±0,09	24,8±0,94	5,50±0,66	33±3,46	74±2,20	321±7,71
P	>0,05	>0,05	>0,05	<0,001	>0,05	<0,05	<0,001
IV	124±10,45	0,80±0,10	27,6±1,72	9,03±0,69	29±1,30	53±2,20	245±22,12
P	>0,05	<0,05	<0,01	<0,001	<0,05	<0,005	<0,001

Legend. Here and in Table 2, P denotes significance of difference compared with initial state.

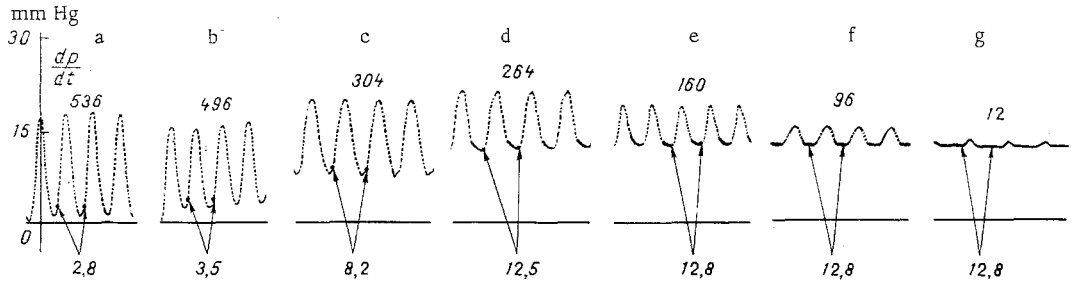

Fig. 1. Dynamics of intraventricular pressure during development of ARI syndrome (a-g). Numbers above curves show rate of change of intraventricular pressure during diastole (in mm Hg/sec); numbers below curves show absolute value of EDP. Arrows indicate time of measurement of EDP.

Investigation of intraventricular pressure curves for animals of this group showed that an increase in EDP usually is accompanied by a gradual decrease in the rate of relaxation of the myocardium (Fig. 1). Evidence of this is given, in particular, by the fall in the value of dp/dt in diastole. Against the background of delay of diastole, the next contraction of the ventricular myocardium took place at a time of incomplete diastole, when EDP was 3.5-13 mm Hg (instead of 0-3 mm Hg in the initial state). Against the background of the slower rate of diastole, the rate of ventricular systole fell steadily more and more.

Investigation of the dynamics of p_aO_2 in the stages of the process indicated above revealed an increasing tendency toward arterial hypoxemia, which was most marked in stages III and IV, and hypocapnia, which reached a maximum in the terminal stage. The mean level of P_aO_2 fell progressively under these circumstances and was significantly below its initial level as early as in stage II.

Analysis of the results revealed correlation between some parameters characterizing the cardiodynamics and pulmonary gas exchange. Correlation between EDP and P_aO_2 also is shown by Fig. 2. Characteristic regions of distribution of the parameters are clearly differentiated in each stage of the process except stage I, in which a considerable range of their changes was observed.

It will be clear from Fig. 2 that in stages II-IV, with the rise of end-diastolic pressure, the level of P_aO_2 continued to fall steadily; in turn, this points to a decrease in the diffusion capacity of the lung tissue.

Traumatic injuries of the chest thus disturb not only the gas-exchange function of the lung, but also the contractile properties of the myocardium. As it progresses, the dysfunction of the left ventricular myocardium noted above, despite a compensatory increase in MSP in the right ventricle, may create a basis for the development of acute congestive manifestations in the pulmonary circulation and increased pressure in the pulmonary capillaries. The latter is known to contribute to the formation of interstitial and intraalveolar edema [11, 12]. By aggravating noncardiac (primarily pulmonary) edema, this cardiogenic mechanism of pulmonary edema depresses the efficiency of the pulmonary gas exchange even more, and this was most marked in stages III and IV,

TABLE 2. Cardiodynamics and Arterial Blood Gas Composition in Dogs with Contusion of the Lung and Injury to the Chest Wall (Convalescence, M ± m, n = 18)

Stage of post-traumatic process	CI, ml/kg·min	SI, ml/kg	MSP	EDP	p_aCO_2	p_aO_2	p_aO_2
					mm Hg		
Initial	125±8,42	1,02±0,09	22,4±0,90	0,98±0,26	31±1,48	88±1,89	450±7,03
I	90±5,31	0,70±0,05	25,6±1,28	3,23±0,84	27±3,03	74±1,08	367±29,59
P	<0,005	<0,005	>0,05	<0,05	>0,05	<0,005	<0,05
II	139±12,53	0,98±0,15	24,6±1,54	2,60±0,56	30±1,43	84±2,12	407±18,16
P	>0,05	>0,05	>0,05	<0,05	>0,05	>0,05	>0,05
III	120±5,11	0,93±0,04	24,8±1,31	1,96±0,71	32±1,73	83±1,28	455±15,72
P	>0,05	>0,05	>0,05	>0,05	>0,05	>0,05	>0,05

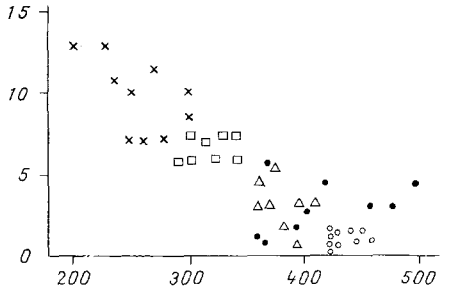

Fig. 2. Correlation between EDP in right ventricle and P_aO_2 at end of 15-min inhalation of 100% O_2 in experimental model of ARI syndrome. Abscissa, P_aO_2 (in mm Hg); ordinate, EDP (in mm Hg). Empty circles – initial state, filled circles – stage I, triangles – stage II, rectangles – stage III, crosses – stage IV.

when the arterial hypoxemia reached its peak. In these same periods a "vicious circle" may evidently be formed from arterial hypoxemia and the increased end-diastolic pressure in the ventricle.

Analysis of the results showed that under the conditions studied the decrease in SI in some experiments did not lead to a decrease in CI because of marked tachycardia. It must be assumed that it is this form of acute heart failure, known in the literature as cardiac failure with high ejection [4, 6, 10], because of stasis of blood in the pulmonary capillaries and their overfilling, may contribute to the formation of pulmonary edema and to the development of the ARI syndrome as such.

In the convalescence group, exposure to the same traumatic factors in the first stages of the experiment caused changes in cardiorespiratory function similar to those indicated above, so that in these animals also the corresponding stages I and II of the post-traumatic process could be distinguished (Table 2). In the next period (stage III), however, the dynamics of the parameters in the convalescent group differed in principle from that in dogs with the ARI syndrome: in this period, which lasted 2-7 days or more, complete (or almost complete) and sufficiently synchronized restoration of the level of the parameters of the cardiodynamics and pulmonary gas exchange which were studied. It can be postulated that the degree of dysfunction of the myocardium and of the pulmonary gas exchange in these experiments was insufficient to cause the development of the hypoxic "vicious circle" that caused death of the animals of the first group.

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EFFECT OF POST-TRAUMATIC FLUCTUATIONS OF ARTERIAL PARTIAL OXYGEN PRESSURE ON INTENSITY OF LIPID PEROXIDATION IN THE LUNG, LIVER, AND MYOCARDIUM OF RATS WITH LUNG CONTUSION

V. I. Kulitskaya and G. V. Murzin

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A frequent complication of closed chest injury is the development of respiratory insufficiency of arterial hypoxemic type [6, 12], accompanied by metabolic disorders in the tissues [5]. Many mechanisms of these disorders have not yet been studied. In particular, we have no data on the changes in intensity of lipid peroxidation (LPO), activation of which accompanies many pathological states [2, 7, 8, 14] and depends on the partial pressure of oxygen (pO_2) [4, 15].

The main aim of the present investigation was to determine the effect of post-traumatic fluctuations of pO_2 in blood flowing to the tissues, i.e., the partial pressure of oxygen in arterial blood (p_aO_2), on LPO in the lungs, myocardium, and liver in the acute period of closed chest injury.

EXPERIMENTAL METHOD

Experiments were carried out on 155 male Wistar albino rats weighing 250-300 g. Closed chest injury (contusion of the lungs) was produced in animals fixed with the chest uppermost, under ether anesthesia by a shot from a pistol, to the spring of which a plate 20 mm long, 5 mm wide, and 5 mm thick was soldered through a rod. A blow of equal force was applied to the chest at a distance of 1 cm to the right of the sternum (along the sternum).

The value of p_aO_2 was measured in the rats of group 1 on a micro-Astrup apparatus (from Radiometer, Denmark). Arterial blood was taken by puncture from the left ventricle of rats fixed in the prone position before trauma as in the rats of group 1, and LPO was studied after decapitation (5-10 rats at a time) in homogenates of myocardium, liver, and lungs by estimation of the reaction product of decomposition of peroxides, namely malonic dialdehyde (MDA) with thiobarbituric acid [2] per milligram protein, estimated by the method in [2]. The rate of lipid peroxidation was taken to be the ratio between the quantity of MDA formed in the sample after incubation for 2 h at 37°C and the MDA content before incubation. The results were analyzed by computer, using Student's test.

EXPERIMENTAL RESULTS

At autopsy during the first few hours after trauma hemothorax was found in 48% of the rats, and all of them had pleural and subpleural hematomas in the superior and middle lobes of the right lung, which began to absorb

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