Hemodynamic Mechanisms of Reduction of Venous Return and Pulmonary Circulation during Experimental Myocardial Ischemia

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Ischemia of left ventricular myocardium in cats moderated blood flow in the venae cavae and decreased venous return, which leads to a drop of blood flow and blood pressure in the pulmonary artery. Shifts in the right atrial pressure had no effects on changes in venous returns. After elevation of the left atrial pressure, promoted by a decrease in contractility of the left ventricular myocardium, blood pressure in the pulmonary artery decreased to a lesser extent than pulmonary blood flow, but did not correlate with shifts in pulmonary vascular resistance.

Key Words: *myocardial ischemia; venous return; blood pressure; blood flow; pulmonary artery; cardiac hemodynamics*

When examining the effect of myocardial ischemia on the hemodynamic indices in systemic circulation, most researchers focus on changes in arterial pressure and cardiac output [3,5,6]. However, the data on the shifts in the blood flow in venae cavae and in venous return under conditions of this pathology do not indicate the reasons underlying reduction of these indices. The degree of interaction between venous return and pulmonary circulation, on the one hand, and parameters of cardiac function in ischemic heart (HR, myocardial contractility, atrial pressure) on the other hand, is also unclear.

Our aim was to study the character and the magnitude of changes (together with underlying mechanisms of these changes) in the blood flow in venae cavae, venous return, pressure and flow in the pulmonary artery, and the parameters of cardiac hemodynamics during experimental left ventricular (LV) ischemia.

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MATERIALS AND METHODS

Experiments were carried out on 12 cats weighing 3.5-5.0 kg. The thorax was opened under nembutal narcosis (35-40 mg/kg intramuscularly) and artificial ventilation was performed with the help of a Fasa-9 apparatus. Blood pressure was monitored in the left femoral artery with a PDP-400 transducer. The pressure in the pulmonary artery was measured with a 2-mm catheter passed via right atrial auricle into the cavity of the right ventricle through the tricuspid and semilunar valves. The pressure values in both atria were measured with Baxter transducers passed into the atria via their auricles. The blood flow in the pulmonary artery was determined with a cuff transducer of a T-106 ultrasound blood flow meter (Transonic). Cardiac output was measured in the ascending aorta by a cuff transducer coupled to an MFV-2100 electromagnetic flow meter (Nihon Kohden). Myocardial contractility of LV was assessed by the maximum of the first derivative of LV pressure dP/dt_{max}, determined with the help of analog differentiating device. LV pressure was measured with a PDP-400 transducer

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connected to a catheter passed into ventricular cavity through the corresponding auricle. The venous blood flows in the anterior and posterior venae cavae were determined with cuff transducers of a T-206 dual channel ultrasound flow meter (Transonic). HR was calculated by *R-R* intervals on ECG recorded in standard lead II. Venous return to the heart was calculated as the sum of blood flow in the anterior and posterior venae cavae. Pulmonary resistance was determined as the ratio of the difference between the mean pressure in the pulmonary artery and in left atrium to blood flow in the pulmonary artery. Total peripheral vascular resistance (TPVR) was calculated as the ratio of the difference between the mean arterial and right atrial pressure values to the cardiac output.

Experimental myocardial ischemia of LV was induced by clamping the common left coronary artery (LCA) or its descending branch [8]. This branch was clamped with a miniature forceps for 30 sec and 15-20 min after recovery of the examined parameters to the baseline level, the branch was clamped again for 60 sec. LCA was clamped in a similar way. The examined parameters (arterial pressure, right and left atrial pressure, blood flow in the pulmonary artery, cardiac output, blood flow in venae cavae, and contractility of LV myocardium) were recorded on an N-338-8P pen-ink plotter.

The data were analyzed statistically using Student's *t* test, standard (Axum 5.0, Math Soft Inc.) and original software.

RESULTS

In 30 sec after myocardial ischemia induced in LCA region or after clamping the descending branch of LCA for 30 and 60 sec, the cats demonstrated similar changes of the examined hemodynamic parameters in value and direction. Thus, during clamping LCA for 30 sec, venous return to the heart decreased by 13±2%, but dropped by 9±2% and 12±3% from the baseline during clamping of the descending branch for 30 and 60 sec, respectively (Figs 1, 2). Since there were virtually no pressor shifts in the right atrium (Tables 1, 2), they produced no effect on changes in venous return, so its decrease was caused by blood flow decrease in the venae cavae. During 30-sec ischemia in LCA region, the blood flow in anterior and posterior venae cavae decreased by 12±2% and 13±2%, respectively. During 30-sec or 60-sec ischemia in the region of LCA descending branch, the blood flow in the anterior and posterior venae cavae decreased by 10±2 or 12±2% and 9±3% or 12±3%, respectively (Fig. 2).

Under these conditions, the blood flow values in the venae cavae decreased practically to the same degree, so their drop could be caused by decreased cardiac output, which was 22±2% after clamping LCA or even smaller after clamping the descending branch of LCA for 30 and 60 sec: 18±5% and 19±4%, respectively (Fig. 1, 2). By contrast, the corresponding shifts in HR (-4±2%, 2±1, and 3±2%) were insignificant (Table 1, 2), so they could not produce a drop in the cardiac output. During clamping LCA for 30 sec or during clamping the descending branch of this artery for 30 and 60 sec, LV contractility decreased by 6±4%, 6±2%, and 9±2%, respectively (Fig. 1, 2). Although such a small decrease in myocardial contractility contributed to moderation of cardiac output, it could not explain this pronounced reduction.

Reduction of blood flow in venae cavae could result from elevation of TPVR by 10±3%, 11±4%, and 9±3% during clamping LCA for 30 sec or during clamping the descending branch of this artery for 30 and 60 sec, respectively (Table 1, 2). In its

TABLE 1. Directivity and Degree of the Changes (%) of Parameters of Pulmonary and Cardiac Hemodynamics during Myocardial Ischemia in LCA Basin in Cats (*M±m*)

Parameter	Duration of ischemia, sec	
	30	60
Arterial pressure	-13±3	-39±5
Pressure in pulmonary artery	-9±2	-13±2
Pulmonary vascular resistance	-6±5	-28±10
TPVR	10±3	-4±2
Pressure in right atrium	4±3	12±4
Pressure in left atrium	10±4	51±8
HR	-4±2	-19±5

TABLE 2. Character and Degree of the Changes (%) of Parameters of Pulmonary and Cardiac Hemodynamics during Myocardial Ischemia in the Region of Descending Branch of LCA in Cats (*M±m*)

Parameter	Duration of ischemia, sec	
	30	60
Arterial pressure	-6±2	-8±2
Pressure in pulmonary artery	-6±2	-6±2
Pulmonary vascular resistance	2±6	4±6
TPVR	11±4	9±3
Pressure in right atrium	-1±3	0±3
Pressure in left atrium	3±2	7±3
HR	2±1	3±2

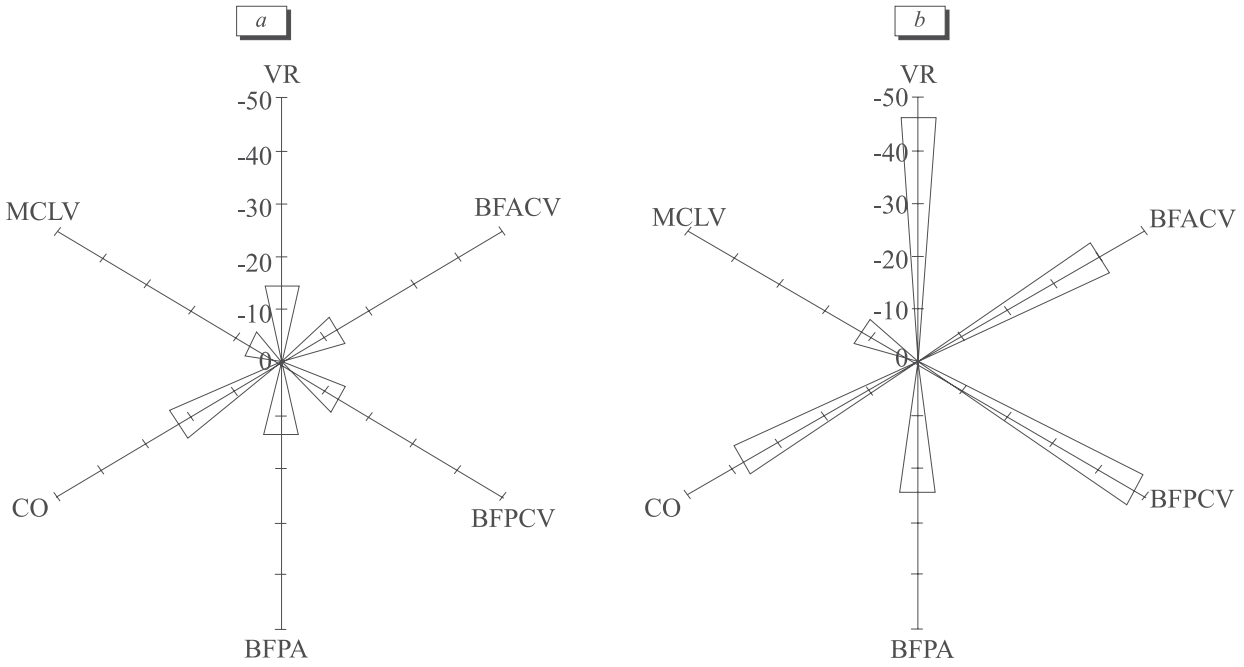

Fig. 1. Directivity and the degree of the changes of blood flow in venae cavae, venous return, and blood flow in the pulmonary artery during myocardial ischemia in LCA region. Here and in Fig. 2: clamping LCA for 30 sec (*a*) and for 60 sec (*b*). VR: venous return; BFACV: blood flow in anterior cava vein; BFPCV: blood flow in posterior cava vein; BFPA -- blood flow in the pulmonary artery. CO: cardiac output; MCLV: myocardial contractility of left ventricle; changes are given in percents of baseline.

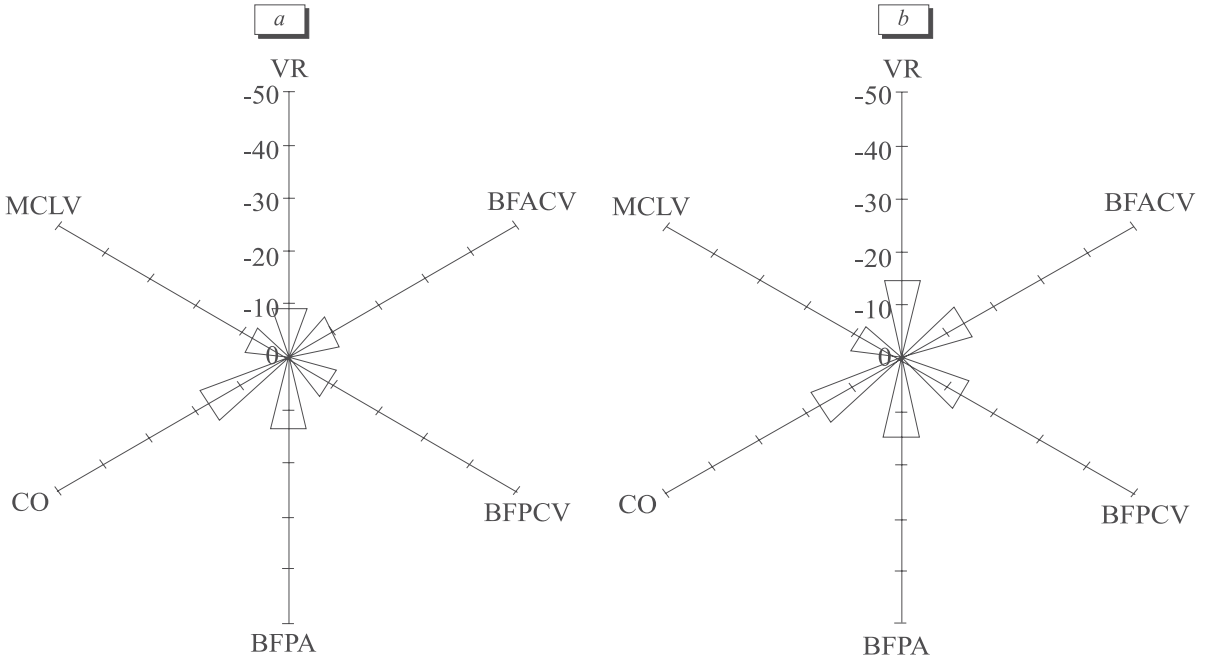

Fig. 2. Directivity and the degree of the changes of blood flow in venae cavae, venous return, and blood flow in the pulmonary artery during myocardial ischemia in the region of descending LCA branch.

turn, this elevation resulted from reflex potentiation of sympathetic influences on the vessels in response to the drop in arterial pressure [4,6,8]. Our experiments showed that short-term (20 sec) occlusion of the carotid arteries (carotid sinus reflex) induced both elevation of arterial pressure by 18±4% or its drop by 15±3% in equal number of observations in cats. Therefore, the neurogenic mechanisms did not underlie the revealed changes in TPVR, which increased because of more pronounced decrease in cardiac output in comparison to that induced by depressor shifts of arterial pressure (Table 1, Fig. 1). Thus, the de-

crease of blood flow in the venae cavae and the drop of venous return did not result from elevation of TPVR.

The most pronounced changes of the examined hemodynamic indices (with exception of TPVR, which did not significantly vary) were observed in cats during myocardial ischemia produced in the region of LCA for 60 sec. Under these conditions, arterial pressure dropped by 39±5%, the blood flow in the anterior and posterior venae cavae decreased by 40±5% and 48±4%, respectively, and venous return decreased by 46±4% (Fig. 1, *b*). It could be hypothesized that the drop in venous return was promoted by pressure elevation in the right atrium by 12±4% (Table 1). However, in previous experiments [2] we showed that under vagal stimulation decelerating HR by 50±4%, and decreasing myocardial contractility by 19±7%, reduction in venous return by 38±3% occurred during right atrial pressure elevation by 34±5% [2]. Thus, insignificant elevation of the right atrial pressure observed during myocardial ischemia could not produce pronounced reduction of venous return. Moreover, during myocardial ischemia the negative chrono- and inotropic effects on the heart were only 19±5% and 12±4% (Table 1, Fig. 1, *b*), which also could not produce marked decrease in venous return. It can be hypothesized that in addition to bradycardia and impaired myocardial contractility, the drop in venous return resulted from deposition of the blood in veins of the splanchnic region [3] due to their dilation in response to NO release from vascular endothelium [5,7].

Under these experimental conditions, the blood flow in the pulmonary artery during 30-sec myocardial ischemia in the vicinity of LCA decreased by 13±3%, while clamping the descending branch of this artery for 30 and 60 sec decreased the blood flow in the respective region by 12±3% and 16±3% respectively, which was roughly equal to the drop in venous return (Fig. 1, *a*; Fig. 2). Since the shifts in pulmonary vascular resistance, which were 6±5% during clamping LCA for 30 sec, and 2±6% and 4±6% during clamping the descending branch of this artery for 30 and 60 sec, respectively, were insignificant (Tables 1, 2) they could not be responsible for the observed decrease in pulmonary circulation. Therefore, the drop of the blood flow in the pulmonary artery during myocardial ischemia resulted from diminution of venous return.

Clamping LCA for 30 sec decreased blood pressure in the pulmonary artery by 13±3%, while clamping the descending branch of this artery for 30 and 60 sec decreased it by 6±2% (Tables 1, 2). In all these cases, the drop of blood pressure in the pulmonary artery was less pronounced than the decrement of pulmonary blood flow (Fig. 1, *a*; Fig. 2). According to Poiseuille equation, pressure in the pulmonary artery depends on the pulmonary blood flow, pulmonary vascular resistance, and blood pressure in left atrium [1]. Clamping LCA for 30 sec elevated the latter value by 10±4%, while clamping the descending branch of this artery for 30 and 60 sec increased it by 3±2% and 7±3%, respectively (Tables 1, 2). In its turn, elevation of blood pressure in the left atrium resulted from abovementioned decrease in LV contractility (Tables 1, 2). Thus, under myocardial ischemia, the smaller value of the depressor shifts in the pulmonary artery in comparison with the decrement of the pulmonary blood flow resulted from the rise of blood pressure in left atrium.

Pronounced decrease in venous return during 60-sec myocardial ischemia in LCA basin yielded greater (in comparison with 30-sec ischemia) decrease in the pulmonary blood flow (26±3%) and in cardiac output (by 38±5%, Fig, 1). At the same time, pressure in the pulmonary artery decreased only by 13±2% (Table 1) despite the negative shift in the pulmonary vascular resistance (-28±10%), which was smaller than the drop of blood flow in the pulmonary artery. Therefore, under these conditions, smaller decrease of blood pressure in the pulmonary artery in comparison with the changes in pulmonary blood flow was also caused by elevation of pressure in the left atrium (by 51±8%, Table 2). The pronounced rise of this pressure resulted from moderation of contractility of LV myocardium by 12±4% (Fig.1, *b*).

Thus, experimental ischemia in LV myocardium decreased the blood flows in venae cavae and diminished venous return, which were the major causes underlying the drops of blood flow and blood pressure in the pulmonary artery. Under these conditions, the changes in TPVR did not correlated with the shifts in the blood flows in the venae cavae and with venous return, while the changes in pulmonary vascular resistance were not linearly related to changes in pulmonary blood flow and pressure in the pulmonary artery. The changes in the right atrial pressure did not affect the changes of venous return, while pressure in the pulmonary artery decreased to a lesser degree than the pulmonary circulation because of pressure rise in the left atrium promoted by a decrease in contractility in LV myocardium. During 60-sec myocardial ischemia in LCA basin, the pronounced negative chrono- and inotropic effects in the heart induced the greater drops in venous return and blood flow and pressure in the pulmonary artery than those

observed during clamping the descending branch of this artery for 30 and 60 sec.

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