CHANGES IN THE CARDIAC OUTPUT AND GENERAL PERIPHERAL RESISTANCE AFTER OBSTRUCTION OF A CORONARY ARTERY

A.V. Vinogradov and L.I. Dmitrieva

Hospital Therapeutic Clinic (Head—A.L. Myasnikov, Active Member of the AMN SSSR) of the I.M. Sechenov Ist Moscow Medical Institute and the Department of Clinical and Experimental Physiology (Head—V.V. Parin, Active Member of the AMN SSSR) of the Central Institute of Postgraduate Medical Training, Moscow
(Presented by V.V. Parin, Active Member of the AMN SSSR,)
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Our national literature contains no published papers regarding the changes in the cardiac output and general peripheral resistance after obstruction of a coronary artery. With the help of a Russian electromagnetic rotameter (type RÉD, model 3103-A) and an apparatus for cardiac catheterization, we made a continuous recording of cardiac output and mean arterial pressure.

EXPERIMENTAL METHODS

Using an animal under intravenous thiopental sodium anesthesia after the preliminary administration of morphine hydrochloride in a dose of 5 mg per 1 kg of weight, we made a longitudinal sternal section (switching the animal to artificial respiration at the requisite moment) to expose the thorax and dissected out the brachiocephalic, left subclavian and both carotid arteries and the aorta, distal to the origin of the left subclavian artery. The femoral artery was also dissected out. Then we exposed the pericardial cavity and, using 2-4 ml of a 2% novocain solution, dissected out the circumflex or descending branch of the left coronary artery.

Next, heparin was intravenously injected in a dose of 5 mg per 1 kg of weight, and the rotameter was attached to the animal as depicted in the diagram, Fig. 1. The plastic tubes were used to connect the aortic end of the left subclavian artery 1 to the inlet opening of the rotameter 2. The proximal section of the femoral artery 3 and the cephalic sections of the carotid arteries 4, 5 were connected with the outlet of the rotameter 6.

When the cannulation had been completed, we opened the clamps on the left subclavian a and carotid b arteries. After the blood flow from the subclavian artery through the rotameter to the carotid arteries was established, the brachiocephalic artery was ligated 7. Then a clamp was immediately placed on the aorta distal to the origin of the left subclavian artery 8, and, simultaneously, the clamp on the femoral artery c was opened. From this time on, the blood from the aorta passed through the left subclavian artery into the rota-

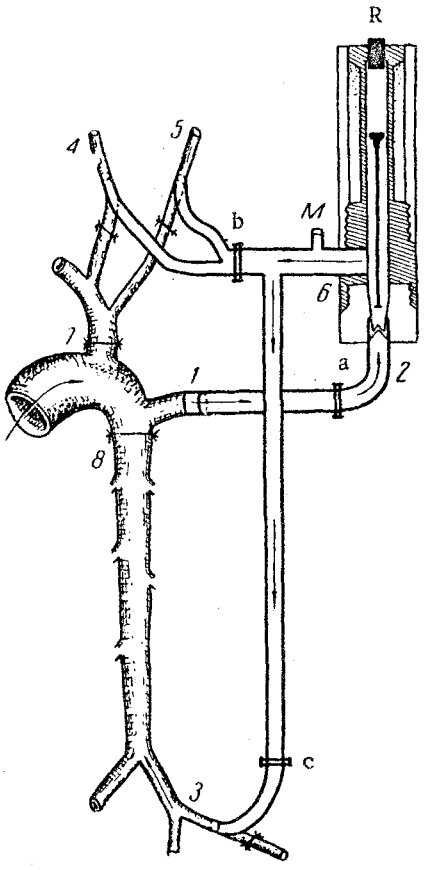


Fig. 1. Diagram showing how rotameter was connected with animal. 1) Aortic end of left subclavian artery; 2) rotameter inlet; 3) proximal end of femoral artery; 4,5) cephalic ends of carotid arteries; 6) rotameter outlet; 7) brachiocephalic artery; 8) place of aortic obstruction [a clamp at rotameter inlet; b) clamp for tubes to carotid arteries; c) clamp on tube carrying blood to femoral artery ; R) rotameter; M) electromagnetic manometer.

meter and, from the latter, went to the carotid and femoral arteries. This provided continuous measurement by the rotameter of the total volume of blood expelled by the left ventricle into the aorta, excluding the blood flowing out from the aorta into the coronary arteries.

Three to five minutes after constriction of the aorta, when a constant value had been established for the blood flow through the rotameter, we began to record the curves of the volumetric blood flow and the mean blood pressure on a POB-14 oscillograph. A Moskite* clamp was applied at the mouths of the dissected-out branches of the left coronary artery during the continuous recording of these curves. After developing the photographic record, we studied the changes which developed in the volumetric blood flow and the mean blood pressure.

It is evident from Green's studies [3] that the correlation between the height of the pressure and the volume of the blood flow in the artery is in the form of a parabola which curves toward the axis of the pressure. High pressure in the tubes causes extra stimulation of the myocardium due to the increase it causes in the volume of the coronary blood flow. The diameter of the plastic tubes, therefore, has to be such that the mean arterial pressure inside them is 80-100 mm of mercury with a normal animal. The external appearance of the coronary arteries is a good index of how correctly this question has been decided. The coronary arteries should look the same before and after cannulation of the large arteries. Any visible distention of the coronary arteries with blood due to a passive increase in their diameter indicates that the mean arterial pressure in the tube system is not correct.

EXPERIMENTAL RESULTS

Thirty-six experiments, ten of which were preparatory, were performed by the method described. Oscillograms from 19 experiments were used to analyze the hemodynamic disturbances (see table). In four experiments (19, 21, 22 and 23), we reproduced successive obstruction of the circumflex and descending branches of the left coronary artery. The observations are brief due to the early development of ventricular fibrillation.

In 18 out of the 19 experiments, obstruction of the coronary artery was attended by a decrease in the output of the left ventricle; this decrease either developed gradually, becoming clearly evident after the first 20-60 seconds, or developed acutely immediately after the application of the clamp (Fig. 2).

In six experiments, the cardiac output remained constantly reduced during the entire observation period. In 12 experiments, it rose to the original level at different intervals following the obstruction, either from time to time (in 10 experiments) or stably (in one experiment). After an initial decrease, the cardiac output in experiment 24 not only regained, but at times even exceeded by 8.6% the maximal value of the original period; this evidently should be regarded as a manifestation of hypercompensation of the heart's contractile function.

In four experiments, we attempted to produce a stabler and more pronounced decrease in the output by increasing the mass of ischemic tissue. Obstruction of the second branch of the left coronary artery was attended by a more acute decrease in the output, but ventricular fibrillation developed in three experiments soon after the application of the second clamp. The results of the longer lasting experiment 22 showed that the capacity of the unaffected myocardium to maintain the output at the former level was not exceeded even after obstruction of the mouths of both branches of the left coronary artery.

The changes in the mean blood pressure generally reflected the changes in output. In 11 experiments (3, 7, 8, 10, 12, 15, 17, 19, 21, 22 and 24), the blood pressure and output decreased simultaneously. In seven experiments, the blood pressure remained somewhat lowered, but, in ten experiments, increased briefly or stably to the original level. In experiment 18, the mild decrease in output which occurred after obstruction of the coronary artery was not attended by any fall of the blood pressure, which toward the end of the experiment had become even higher than during the control period. The variations in output and blood pressure observed in experiment 14 were no greater than the variations observed in these values during the control period.

In spite of the brevity of the observations, one can assume that obstruction of a coronary artery under these

* Transliteration of Russian — Publisher.

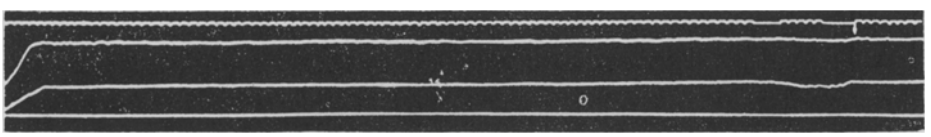


Fig. 2. Change in output and mean blood pressure after obstructure (↓) of circumflex branch of left coronary artery. Experiment 20 (August 22, 1958). The output decreased from 22.8-22 to 18.5 ml/sec after obstruction of the artery. The blood pressure fell from 92 to 87 mm after 3 seconds and then to 85 mm of mercury after 40 seconds. Curves (from top to bottom) show: time in seconds; mean blood pressure; output of left ventricle; zero line. Paper moving from right to left.

Changes in the Hemodynamic Indices after Obstruction of the Coronary Artery

Experiment	Initial deviations: cardiac output: decreases	Initial deviations: cardiac output: no changes	Initial deviations: mean arterial pressure: fall	Initial deviations: mean arterial pressure: no changes	Initial deviations: general peripheral resistance: increase (in % of maximal original level)	Initial deviations: general peripheral resistance: no changes	Deviations during experiment: cardiac output: restoration: to original level: stable	Deviations during experiment: cardiac output: restoration: to original level: periodic	Deviations during experiment: cardiac output: periodic increase over orig. level	Deviations during experiment: cardiac output: stable decrease	Deviations during experiment: cardiac output: no conclusive fluctuations	Deviations during experiment: mean arterial pressure: increase: to original level: stable	Deviations during experiment: mean arterial pressure: increase: to original level: periodic	Deviations during experiment: mean arterial pressure: periodic increase over orig. level	Deviations during experiment: mean arterial pressure: stable fall	Deviations during experiment: mean arterial pressure: no conclusive fluctuations	Deviations during experiment: general peripheral resistance: constant	Deviations during experiment: general peripheral resistance: increase: with periodic decreases: to original level	Deviations during experiment: general peripheral resistance: increase: with periodic decreases: below original level	Deviations during experiment: general peripheral resistance: no changes	Duration of observation after obstruction
3	+		+		121,2					+			+					+			1min. 17sec.
5	+		+		259,7			+					+						+		0,9 sec.
6	+		+		123,4					+					+				+		33min.
7	+		+		110,4			+				+						+			4 min. 36sec.
8	+		+		—	+				+					+			+			57sec.
10	+		+		103,6					+					+				+		2 min. 48 sec.
12	+		+		108,5			+					+					+			2 min.
13	+		+		101,8			+							+			+			1 min. 22 sec.
14	—	+	—	+	—	+					+					+				+	1 min. 18 sec.
15	+		+		—	+		+					+							+	60min. 05sec.
17	+		+		107,6			+					+					+			16min.
18	+		—	+	101,8		+							+				+			34min.
19a	+		+		106,3			+					+					+			} 30min. 15sec.
19б	+		+		113,7 *					+					+			+			
20	+		+		110,2					+					+		+				2 min.54 sec.
21a	+		+		116,1			+				+						+			} 26 min.
21b	+		+		135,7 *					+			+					+			
22a	+		+		103,4			+					+					+			} 75 min.
22b	+		+		128,7 *			+					+					+			
22c	+		+		134,6 *			+					+					+			
23a	+		+		106,7			+							+			+			} 5min. 03 sec.
23b	+		+		1 32,9*					+					+				+		
24	+		+		115,3				+				+					+			1 min. 30 sec.
26	+		+		111,5					+					+			+			2min. 33 sec.

*After the double obstruction, the general peripheral resistance was computed in relation to its value before application of the clamp.

specific experimental conditions causes a temporary decrease in the cardiac output and the mean blood pressure.

The deviations of the experimental hemodynamic indices from the original values were variable, even diametrically opposite to each other in some experiments. To explain the role of the cardiac and vascular factors in the hemodynamic disturbances which developed, the general peripheral resistance was determined according to the formula:

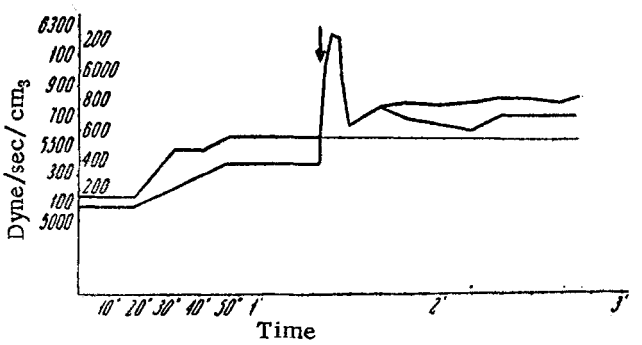
$$GPR = \frac{Mm \cdot 1332}{O},$$

where GPR is the general peripheral resistance in absolute units, Mm is the mean arterial pressure in millimeters of mercury and O is the cardiac output in milliliters per second; 1332 is the coefficient by means of which, according to one of the accepted international systems for measuring physical values (C.G.S. system), units of resistance are converted into absolute units (dyne · sec/cm^5

Immediately after obstruction of the coronary artery, the general peripheral resistance increased markedly in 16 experiments, indicating an attendant increase of the vasomotor tonus in the systemic circulation. As one of the authors of this article has reported in [1], the venous supply to the heart remains ample in experimental myocardial infarction. On this basis, it would seem that the decreased output observed in our experiments was due to primary affection of the contractile function of the heart. This is also suggested by the prior decrease of the output observed in several experiments.

Despite the sometimes clearly apparent fall of the mean arterial pressure, the general peripheral resistance was observed to increase in all 16 experiments. Therefore, the fall of arterial pressure was not due to lowered vascular tonus or to any insufficiency of the venous supply, but was, in the final analysis, a hemodyamic manifestation of primary affection of the contractile function of the heart. The hemodynamic disorders observed would seem to be unique in character, as this type of disorder does not occur in shock or paresis of the vasomotor tonus.

Peripheral resistance to the blood flow increased after the obstruction, but in only one experiment did it remain increased throughout the observation period (Fig. 3). In 15 experiments, it quickly returned to the original level. However, no stable restoration of the original correlations between pressure and output was observed. In 12 experiments, the peripheral resistance again increased and remained so, although it periodically decreased to the original level. In experiment 8, the general peripheral resistance initially remained within the original range, but increased somewhat toward the end. No conclusive fluctuations in the peripheral resistance were observed in experiment 14.



↓ Obstruction of circumflex branch of left coronary artery

Fig. 3. Increase in the general peripheral resistance after obstruction of the circumflex branch of the left coronary artery. Experiment 20 (August 8, 1959).

Therefore, we observed a stable or periodic increase in the general peripheral resistance in 17 out of 19 experiments. The increase of the vasomotor tonus in the systemic circulation is evidently as typical a consequence of coronary artery obstruction as is the decrease in output. The four experiments with successive obstruction of the circumflex and descending branches of the left coronary artery provided especially convincing confirmation of this conclusion. Each time, obstruction of the large branch was attended by a sharper increase in the general peripheral resistance.

There was no apparent change in the general peripheral resistance in three experiments, which indicates that an increase in vasomotor tonus is evidently not a universal, although an extremely frequent, reaction of the vascular system to obstruction of a coronary artery. Our continuous registration of the hemodynamic indices showed other indications of the complex nature of the changes observed in the vascular tonus. In two experiments (5 and 23) on a background of sharply increasing peripheral resistance, there were brief periods (lasting 1 and 6 seconds) in which it fell considerably below the original level. The single decreases of the peripheral resistance observed in experiments 6 and 10 were less conclusive.

Our experimental methods permit only a summary evaluation of the vasomotor changes in the systemic circulation. The increased general peripheral resistance observed in the majority of cases could be due to a predomination of vasoconstrictor processes, possibly in only certain vascular regions, over vasodilatation or unchanged vascular tonus in other regions of the organism. The antipodal fluctuations of the general peripheral resistance, which sometimes lasted several seconds, can only be caused by the interaction of conflicting trends of vasomotor changes with a brief predomination of the vasodilatation processes, probably in certain vascular regions, over the vasoconstrictor processes in others.

In the literature available to us, we found only two works studying the regional of the vascular tonus in experimental myocardial infarction. According to M.N.

Levy and A.L. Frankel in [4], obstruction of a coronary artery is always attended by an increase in the resistance to the blood flow in a dog's posterior extremity. Bing and co-workers [2], in one series of experiments, observed decreased resistance in the coronary circulation, evidently indicating active dilatation of the coronary arteries.

Comparison of our experimental results with the literary data allows us to hypothesize that obstruction of a coronary artery is attended by complex reorganization of the tonus in different vascular regions of the systemic circulation, owing to which redistribution of the reduced cardiac output is effected. The humoral and reflex mechanisms of this specific reaction of the vascular system to an acutely decreased output, which reaction is also observed in other pathological conditions on models of myocardial infarction, have not yet received sufficient study.

Therefore, the acute decrease in output following obstruction of a coronary artery is attended by a peculiar reorganization of the vascular tonus in the systemic circulation. The rather regular increase in the general peripheral resistance observed in the course of most of the experiments indicates a predomination of the vasoconstrictor processes over the vasodilatation processes. The complex mechanism of the increase in general peripheral resistance helps to redistribute more economically the reduced output, i.e., acts as an adaptational reaction, providing for the maintenance of a more or less stable level of arterial pressure, on the one hand, and for the sustenance of the contractile properties of the unaffected myocardium on the other by increasing the venous supply to the heart and maintaining the maximal possible coronary circulation volume.

SUMMARY

The left subclavicular, both carotid and femoral arteries were shunted; then the brachiocephalic artery and aorta were obstructed, distal to the origin of the left subclavicular artery. The output of the left ventricle, excluding that portion of it which flows into the coronary arteries, entered the rotameter through the left subclavicular artery and flowed into the distal sections of carotid arteries and the proximal sections of the femoral artery. The average blood pressure in the system was measured by an electric manometer. From these data, general peripheral resistance could be estimated according to the data obtained. An average blood pressure of 80–100 mm Hg is the best at which to study the changes of hemodynamic indices occurring after obstruction of the coronary artery.

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