A NEW TECHNIQUE OF GRAPHIC REPRESENTATION OF MYOCARDIAL RESERVE AND RESPONSIVENESS OF PERIPHERAL ARTERIES WHEN CHOOSING THE SURGICAL APPROACH IN PATIENTS WITH MULTIFOCAL ATHEROSCLEROSIS

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The aim of the investigation was to develop a new technique to estimate myocardial and peripheral reserves; and on the basis of the obtained responsiveness indices of coronary and peripheral arteries — to improve the diagnostics and optimize the choice of surgical treatment modality of patients with multifocal atherosclerosis.

Materials and Methods. 296 patients with concomitant lesions of coronary arteries and lower extremity vessels were examined. In 15 patients, according to the findings of synchronously performed stress-echocardiography and ultrasound Doppler of lower extremities, we compared the severity of coronary and peripheral syndromes using the developed technique of graphic representation of ejection fraction and ankle brachial index (initial, load-peak, recovery time 3 min, 6 min later) on phase plane.

Results. The study of the distribution dynamics of the indices of ejection fraction and ankle brachial index — the basic indices of intracardiac regional circulatory dynamics — enabled to distinguish 4 zones: A1 zone — low coronary and satisfactory peripheral reserves, A2 zone — low coronary and peripheral reserves, A3 zone — low peripheral and satisfactory coronary reserves, B zone — satisfactory coronary and peripheral reserves. A surgical approach will depend on the zone the indices of the measured parameters are referred to.

Conclusion. The suggested technique for the assessment of functional coronary and peripheral reserves by means of graphic representation of the findings on phase plane enables to specify the indications to surgical management and prognosticate ischemic complications.

Key words: concomitant lesions of coronary arteries and the arteries of lower extremities; ejection fraction; ankle brachial index; staged or single-stage operations in multifocal atherosclerosis.

The consistency of arterial bed involvement and the severity of clinical presentations of the corresponding ischemic syndromes determine the significance and relevance of the atherosclerosis problem [1]. The presence of peripheral atherosclerosis presupposes high probability of combined involvement of coronary arteries [2, 3]. The prevalence of arterial sclerotic diseases of lower extremities among the population of developed countries varies from 4.3 to 18% depending on age [4, 5]. The increase of death rate occurs due to various comorbidities. Acute myocardial infarction risk has been found to be considerably higher in patients with concomitant diseases of peripheral arteries. In these patients a positive stress-test is revealed in 66% of observations, and 80% of patients have the involvements of at least one coronary artery, myocardial infarction risk increasing up to 60%. Death rate in patients with critical lower limb ischemia within the first year is 25%, in patients with amputations — up to 45% [1]. According to other sources, only 10% of patients with peripheral atherosclerosis have no involvements of coronary arteries [6]. In patients with combined atherosclerotic involvements of coronary arteries and the arteries of lower extremities after aortocoronal bypass (ACB) the risk of acute coronary syndrome, stroke or death is higher than in a group of patients with intact low limb arteries [7, 8]. In contrast, the patients after ACB in the late period are likely to have critical lower limb ischemia and the need for vascular surgery [9]. In addition, the choice of surgical approach in concomitant lesions of coronary bed

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and peripheral arterial beds up to the present day is under debate, and the key point is the determination of optimal sequence of revascularization stages or the performance of a single-stage operation [10]. Thus, according to D. Poldermans et al. [11], in high coronary risk patients, preventive myocardial revascularization did not improve the treatment results. In contrast, the study [12] of high risk patients showed the primary or a one-stage myocardial revascularization to be the prerogative of choice in the combination of surgical intervention and endovascular or hybrid operation. D. Miklos et al. [13], give evidence indicating no reduction of perioperative mortality or long-term death rate in concurrent operations with primary myocardial revascularization.

The lack of agreement of opinion on the multifocal atherosclerosis management is due to different views on hemodynamic conditions in affected beds, with the views being gained in the assessment of clinicoanatomical criteria alone using statistical diagnosis without regard to functional possibilities of the organs. Therefore, as to clinical picture, precise diagnosis and quantitative assessment of chronic arterial insufficiency are of great importance.

The aim of the investigation was to develop a new technique to estimate myocardial and peripheral reserves; and on the basis of the obtained responsiveness indices of coronary and peripheral arteries – to improve the diagnostics and optimize the choice of surgical treatment modality of patients with multifocal atherosclerosis.

Materials and Methods. Over the period from 1994 to 2011 we examined 296 patients with concomitant lesions of coronary arteries and lower limb vessels. The patients aged from 35 to 76 years, mean age being 54.7±8.1 years. Clinical presentations of coronary syndrome had the following picture: 31 patients (10.4%) had "latent" myocardial ischemia; effort angina of functional class (FC) I according to the classification of Canadian cardiological association was found in 17 (6.3%), FC II — in 113 (42%), FC III — in 114 (42.4%), FC IV — in 25 (9.3%) of patients. Unstable angina was revealed in 1 patient (0.3%), postinfarction cardiosclerosis — in 94 (31.7%). According to A.V. Pokrovsky classification, chronic arterial insufficiency of lower extremities of I degree was found in 4 patients (1.4%), II A — in 44 (14.9%), II B — in 173 (58.4%), III — in 74 (25%), IV — in 6 (2%). 11 patients had abdominal aortic aneurysm.

The basic diagnostic techniques were ultrasonic dopplerography (USDG) at rest and duplex scanning, electrocardiography (ECG), Holter monitoring of ECG, bicycle ergometry (BE), echocardiography (echoCG), multispiral computed tomography angiography (MSCTA), coronary angiography, digital subtraction angiography. Besides standard techniques, in 15 patients with different severity of multifocal atherosclerosis we used a new method based on synchronous performance of stress-echoCG and USDG of lower limb arteries [14]. Bicycle ergometric method in prone position was used as a stress-test to provide optimal conditions of cardiac imaging and the best approach to study the arteries of lower extremities.

The patients were examined in the morning on an empty stomach. On examination day nitrates, β-blockers were discontinued. Before the stress test there were performed duplex scanning of lower limb arteries and dopplerographic test. The quantitative assessment was conducted at rest: the flow was located in femoral artery, posterior tibial artery in the medial ankle zone, and arteria dorsalis pedis in the first interdigital space. Flow parameters were estimated at rest. Simultaneously we measured arterial pressure (AP) using hand sphygmomanometer in brachial, femoral arteries and in lower extremity at ankle level. AP was measured at rest, at the end of the 3rd minute of stress, and every minute in the period of recovery of parameters up to initial level. We calculated resting pressure gradients and indices. In the meantime, another researcher performed resting stress-echoCG. We assessed systolic function of the left ventricle (LV) calculating end-diastolic, end-systolic, stroke volumes and ejection fraction (EF) of LV, LV regional contractility (WMS — contractility index), LV diastolic function (DT — time of early diastolic drop of transmitral flow rate, E/A — the velocity ratio of transmitral flow in LV early filling phase and atrial systole phase).

Then there was the session of one-stage bicycle ergometric load within 3 min with threshold power of 50 W, which is optimal for patients with lower limb ischemia. After stress test there were repeated echoCG, ECG, USDG with flow location in dorsalis pedis artery in the first interdigital space. We estimated parameters of intracardiac hemodynamics and peripheral blood flow. The test was terminated prematurely if there appeared clinical presentation of angina pectoris, ischemic changes on ECG, high arterial hypertension (systolic AP above 200 mm Hg or diastolic AP above 100 mm Hg), fatigue and pains in calf muscles. In the recovery period we measured echocardiographic parameters every 3 min and AP measurements and blood flow rate every other minute till initial echocardiographic and dopplerographic parameters recovered. We studied the parameters recorded at rest, peak-load and in the recovery period, and compared the severity of coronary and peripheral syndromes using the developed technique of graphic representation of EF values and ankle brachial index (ABI) (initial, load-peak, recovery time: 3 min, 6 min later) on phase plane.

One-artery region operations were performed in 210 patients (70.9%), two-stage revascularizations of myocardium and lower extremities — in 74 (25%), single-stage surgeries — in 12 patients (4%). 56 patients underwent endovascular treatment.

Results. To assess regional hemodynamics we analyzed the values of the ankle regional systolic pressure index depending on walking time (Fig. 1). If walking time is taken as a subjective index, the obtained histogram should be interpreted as follows: ABI value depends on the degree of intermittent lameness, with the index growth the walkable distance increase. The highest information value of the test was obtained in patients with intermittent lameness after walking 50, 150, 200 m.

In patients with critical lower limb ischemia and in those with compensated blood flow there were obtained significant standard deviations: the patients with similar index values differed in walking time. False-negative USDG results were found in 7 observations. Mean ABI values were 0.72±0.05 in

II A ischemia stage and 0.51±0.07 — in II B stage ($p<0.05$). In III stage of chronic arterial insufficiency (CAI) ABI was 0.24±0.11 that statistically significantly differed from II stage of the disease. The investigation carried out has proved resting USDG to be less informative in patients with compensated blood flow of lower limbs.

Using a synchronous stress test in 15 selected patients we studied the main quantitative parameters of LV systolic function, peripheral blood flow rate, pressure, pressure indices, as well as the values of their reduction after stress, relative to initial level and recovery time.

By means of the discrimination method of values on phase plane we studied the dynamics of EF and ABI distribution on stress and in the recovery of their values up to initial ones for each of 15 patients (Fig. 2). According to the dynamics of these parameters, the patients were divided into two groups taking into consideration the severity of coronary syndrome. The group 1 patients were found to have the aggravation of LV systolic dysfunction on physical exertion, and in patients with multi-vessel disease of coronary bed were revealed to have reduced coronary reserve. The dynamics of values of the group 2 patients is black-colored and indicates high coronary reserve and variable regional hemodynamics due to stenosis degree and the lesion site of lower limb arteries. The study of the dynamics of stress USDG parameters in both groups showed the reduced ankle AP and ABI depending the intensity of atherosclerotic changes in lower limb arteries. The time of recovery to basic data of blood flow values in lower limb arteries depended on the extension, degree of involvement, and the condition of coronary bed. 4 patients with segmental involvement had three-minute recovery time, 2 patients with multiple lesions — from 3 to 6 min. In 3 patients with diffuse lesion of lower limb arteries with distal parts involved the blood flow recovery to initial values occurred 9 min later. In two patients of group 1 with low coronary reserve the peak-load values of regional hemodynamics approximated collateral murmur, and recovery time of initial values was over 12 min indicating low spare capacities in both beds. The detailed values of intracardiac and regional hemodynamics parameters differed in such a way that we could divide them into 4 zones (Fig. 3).

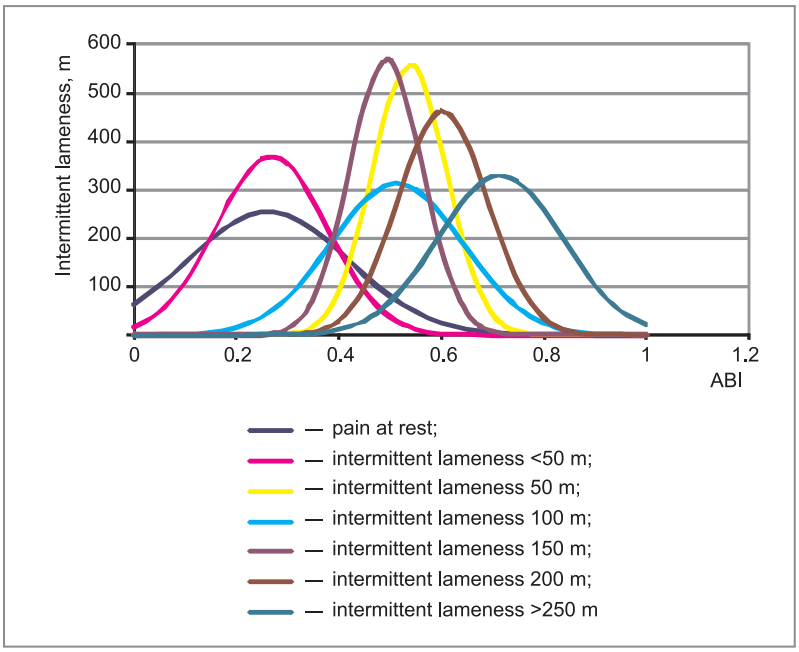

Fig. 1. The distribution of ankle brachial index values depending on the degree of intermittent lameness (n=269)

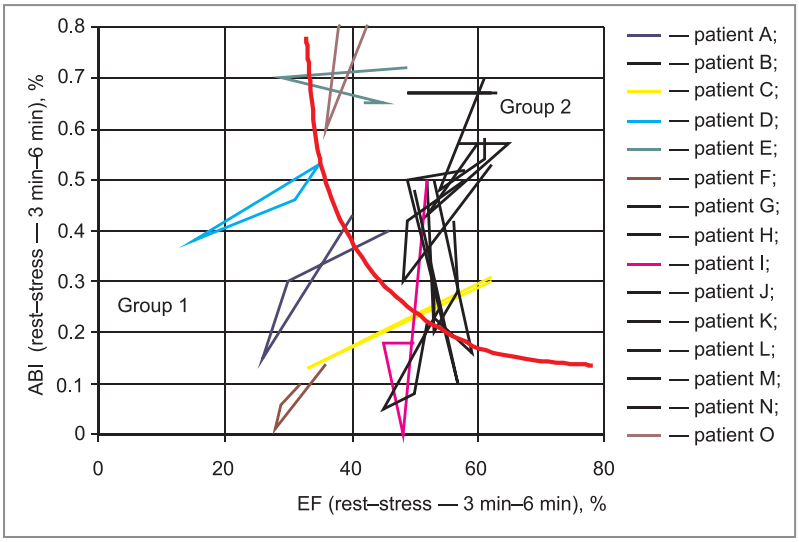

Fig. 2. The distribution of the values of ejection fraction and ankle brachial index on phase plane

The diagram showing EF and ABI values obtained for one patient (See Fig. 3) indicates the points of rest, peak-load and recovery on the third and sixth minutes forming a conditional triangle. If the most part of a triangle is located in one marked zone or another, it will correspond to a certain degree of impaired coronary and peripheral reserves and characterize the condition of coronary and peripheral syndromes: A1 zone — the area of low coronary and satisfactory peripheral reserves, A2 zone — low coronary and peripheral reserve, A3 zone — low peripheral and satisfactory coronary reserves, B zone — satisfactory coronary and peripheral reserves.

The choice of treatment modality will be determined by the position of the resulting geometric figure in one of the diagram zones. Based on the division of patients with combined atherosclerotic lesions, the surgical approach is divided into one-stage operations in two beds and staged or isolated operations in each vascular bed. A patient with low coronary and peripheral reserves (A2 zone) has indication

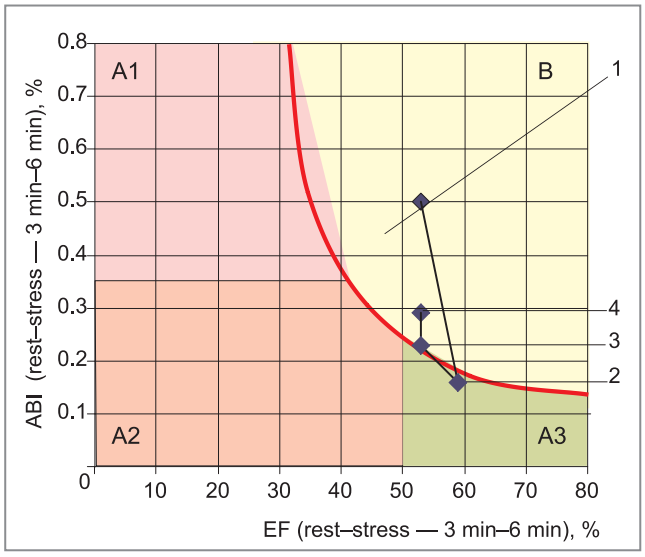

Fig. 3. The distribution of ejection fraction and ankle brachial index values on phase plane for 4 zones. There is a biplanar diagram, the dimension of X-axis corresponds to EF, and Y-axis – to ABI values. The diagram space is divided into four zones: the zone of low EF and satisfactory ABI (A1), the zone of low EF and low ABI (A2), the zone of satisfactory EF and low ABI (A3) and the zone of satisfactory EF and satisfactory ABI (B). The diagram represents Patients M. data: rest point (*1*), peak-load pint (*2*) and the points of recovery of the 3rd (*3*) and 6th (*4*) minutes. A triangle or a geometric configuration close to a triangle has been obtained

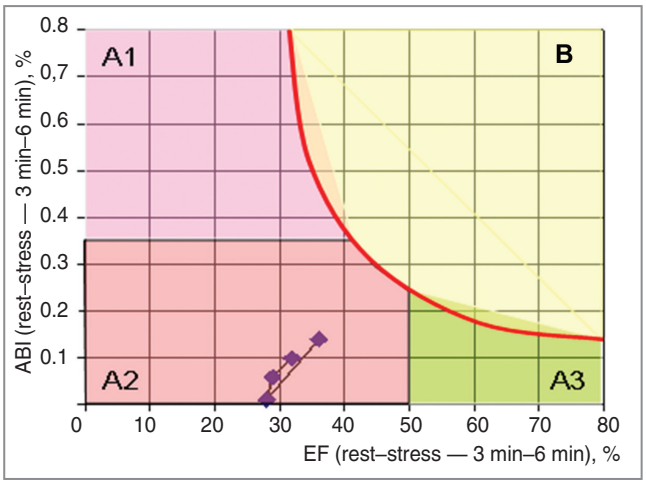

Fig. 4. Surgical approach taking into account the distribution of ejection fraction and ankle brachial index values on phase plane. A2 zone — a one-stage operation. Patient F. data

for a one-stage operation (Fig. 4). The patients with low coronary reserve and satisfactory peripheral reserve (A1 zone) (Fig. 5), as well as those with satisfactory coronary and peripheral reserve (B zone) (Fig. 6) undergo primary myocardial revascularization, the second stage being the revascularization of lower extremities. In satisfactory coronary reserve and low peripheral reserve (A3 zone) primary repair of lower limb arteries is performed (Fig. 7).

Regarding to clinical picture, the indices of coronary and peripheral reserves reflect the severity of angina pectoris and ischemia of lower limbs, and as a whole, enable to choose a surgical approach rather objectively.

Using the developed technique, the isolated myocardial revascularization was performed in patients with III–IV FC angina, unstable angina, the left main coronary artery stenosis, three-vessel disease combined with lower limb CAI of I–IIA degree. In addition, the patients with CAI of IIB–III degrees, accompanying I–II FC CHD, positive dynamics of EF on loading, one-vessel disease of coronary bed were limited to aorto-iliac zone repair. The presence of marked CHD, EF reduction on loading combined with lower limb ischemia of IIB degree was the indication for sequential staged management with primary myocardial revascularization. If severe CHD was combined with critical

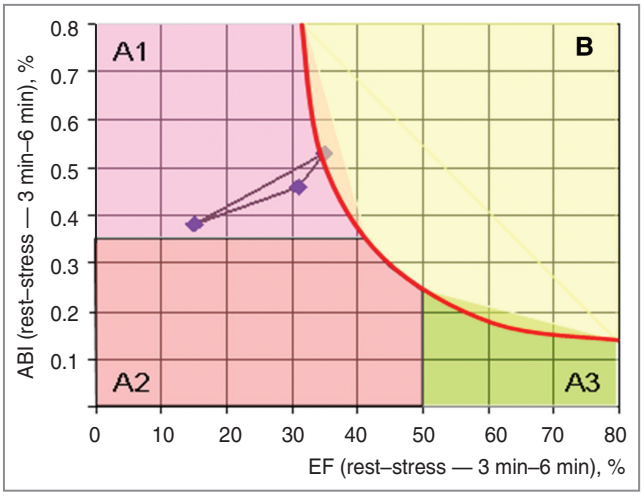

Fig. 5. Surgical approach taking into account the distribution of ejection fraction and ankle brachial index values on phase plane. A1 zone — a staged approach with primary myocardial revascularization. Patient D. data

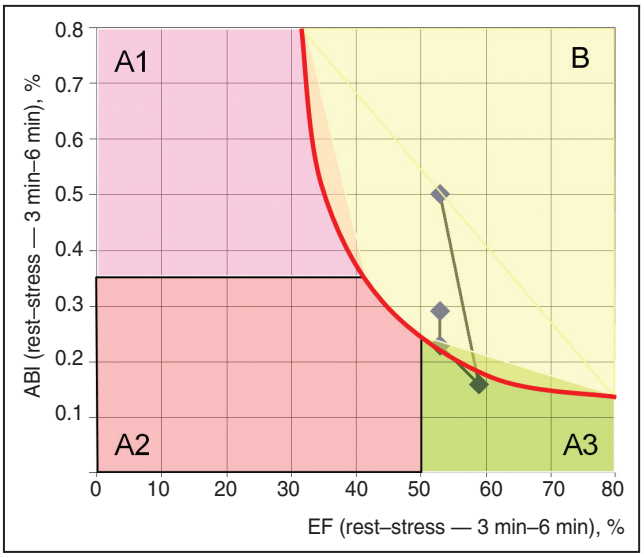

Fig. 6. Surgical approach taking into account the distribution of ejection fraction and ankle brachial index values on phase plane. B zone — a staged approach with primary myocardial revascularization. Patient G. data

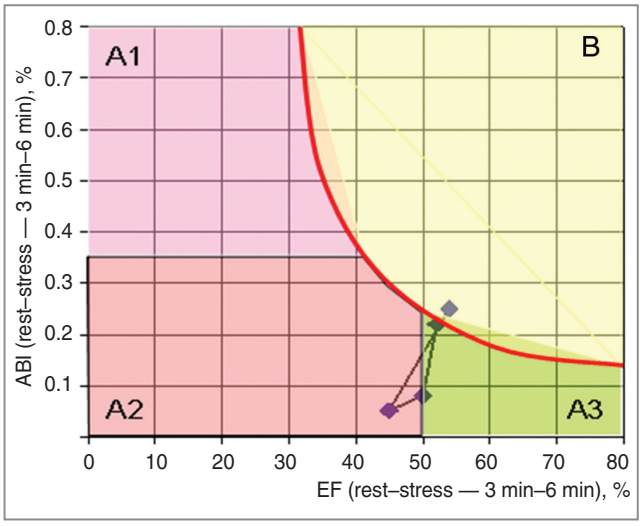

Fig. 7. Surgical approach taking into account the distribution of ejection fraction and ankle brachial index values on phase plane. A3 zone — the revascularization of lower extremities. Patient N. zone

lower limb ischemia, one-stage revascularization was considered to be reasonable.

The suggested graphic representation of the obtained information on phase plane strongly indicates that synchronous investigation of coronary and peripheral reserves should be included into the diagnostic program in case of atherosclerotic lesions of arterial beds. The sensitivity of synchronous stress-echoCG and load USDG of lower limb arteries is 90.9%. Only one patient appeared to have false-negative results of LV ischemic dysfunction in synchronous stress-echoCG. The test was terminated in one patient due to the aggravation of LV ischemic dysfunction before peak-load that is an additional confirmation of the necessity of synchronous study of coronary and peripheral reserves.

Total postoperative mortality was 1.4% (4 from 296 patients). The main causes of lethal outcomes were: acute cardiovascular insufficiency — in 3 patients, acute cerebrovascular accident — in 1 patient. Acute cardiovascular failure occurred after ACB against the background of initial severe coronary syndrome. Therefore, fatal cases happened after myocardial revascularization, mortality being 4.3%. If the staged or one-stage approach was chosen using our method, there were no lethal outcomes.

7.8% of patients (23 from 296) had postoperative complications of various types, among which postoperative lesions in a non-corrected region prevailed: cardial complications in lower limb revascularization, as well as the complications after autovenous withdrawal in ACB. No complications developed in two-stage operations chosen with the help of our technique. A stroke developed in one patient in one-stage revascularization of coronary bed and lower extremities.

Discussion. Noninvasive diagnostics of patients with the involvement of coronary arteries includes ECG, Holter-ECG, echoCG, stress-echoCG, myocardial scintigraphy. As a rule, the combination of clinical presentations and the findings of a noninvasive examination enables to clarify the presence and severity of the disease. Frequently, it is difficult to estimate angina functional class in patients with multifocal atherosclerosis due to limited physical activity of patients, and in patients with critical ischemia it is difficult to carry out stress-tests with physical loading; that prevents from having an idea of an operative risk, from determining the indications for selective coronary angiography. Moreover, the sensitivity and specificity of dobutamine stress-echoCG are 85 and 70% respectively [15]. At the same time, it has been proved that the severity of stress-induced ischemia is associated with operative risk [16].

The most common screening diagnostic techniques of the involvement of lower limb arteries are USDG with ABI determination [17]. To detail the localization of the involved lower limb arteries there used the measurement of segmental pressure on 4 levels, the limitation for the method application is the presence of critical ischemia and venous thrombosis [18].

Common classical diagnostic techniques (e.g., standard treadmill test [1], presenting the details of the lower limb ischemia degree) have low information value to assess the severity of the lesions of vascular beds, the blood circulation condition in the less compromised arterial region. Routine tests cannot furnish the integrated data on functional reserves.

The authors have developed an original diagnostic technique based on a complex synchronous approach to study simultaneously two arterial beds (coronary and peripheral). The technique enables to particularize the data on the intensity and extension of myocardial and lower limb ischemic changes in patients with multifocal atherosclerosis, and quickly receive data on a patient's condition, as well as enables to specify the indications for surgical management, the sequencing of stages, the choice of revascularization method and prognosticate ischemic complications.

Conclusion. The suggested technique for the assessment of functional coronary and peripheral reserves by means of graphic representation of the findings on phase plane enables to specify the indications to surgical management and prognosticate ischemic complications.

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