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БЕЛОРУССКИЙ ГОСУДАРСТВЕННЫЙ МЕДИЦИНСКИЙ УНИВЕРСИТЕТ

КАФЕДРА МЕДИЦИНСКОЙ РЕАБИЛИТАЦИИ И СПОРТИВНОЙ МЕДИЦИНЫ
С КУРСОМ ПОВЫШЕНИЯ КВАЛИФИКАЦИИ И ПЕРЕПОДГОТОВКИ

ФУНКЦИОНАЛЬНЫЕ НАГРУЗОЧНЫЕ ПРОБЫ В РЕАБИЛИТАЦИИ

FUNCTIONAL LOAD TESTS IN REHABILITATION

Учебно-методическое пособие

Минск БГМУ 2026

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Представлена современная информация о функциональных нагрузочных пробах в реабилитации, их классификация, показания и противопоказания к применению, основные методики и техника выполнения процедур.

Предназначено для студентов медицинского факультета иностранных учащихся, обучающихся по специальности «Лечебное дело» по учебной дисциплине «Медицинская реабилитация и физиотерапия».

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LIST OF ABBREVIATIONS

WHO — World Health Organization
MU — metabolic units
PWC170 — Physical Working Capacity
ECG — electrocardiogram
CDH — chronic heart disease
IMGS — individual maximum grip strength
FC — functional class
CHF — chronic heart failure
ICIDH — international classification of disease outcomes
WPW — Wolff-Parkinson-White syndrome

MOTIVATIONAL CHARACTERISTICS OF THE TOPIC

Total class time: 7 hours.

The rehabilitation process begins and ends with an assessment of the patient's functional capabilities. Functional stress tests are used to determine the reserves of the functional systems of the human body. They are understood as research methods in which the system is affected by various factors that change the state of homeostasis to one degree or another. The more economical the response to the effect and the greater its tolerance, the better the quality of life and the lower the likelihood of an exacerbation of the disease. This is what functional stress tests allow us to identify.

The teaching aid presents material on functional stress tests most often used in medicine and recommended by WHO. The need for publishing this teaching aid is determined by the fact that the assessment of the functional state is an obligatory component of the concept of the consequences of diseases, which is fundamental in rehabilitation. And although doctors of different specialties know some means and methods of medical rehabilitation, their use is not always justified due to a lack of understanding of the points of application of these means from the standpoint of improving the functional state of the patient. The publication of this teaching aid is also necessary because there are no textbooks on medical rehabilitation with a section on functional diagnostics.

When assessing the consequences of diseases at the organ level according to the International Classification of Disease Consequences (ICIDH) (dysfunction) in medical rehabilitation, in addition to using various methods of functional diagnostics, it is necessary to conduct load tests. This is due to the need to assess the remaining capabilities of patients before and after rehabilitation, which determines their adaptation and quality of life. The choice of load test depends on

the function of the organ or system, the possibilities of dosing the load, the need to use additional equipment, and methods for assessing the results of the study. The main requirement for load tests is their safety. From this position, tests with physical load are optimal. In rehabilitation, preference is given to tests that allow for a quantitative determination of the degree of loss of function after illnesses or injuries.

Objective of the lesson: assessment of the functional capabilities of the patient's organs and systems, their state of adaptation to various influences.

Objectives of the lesson:

– to determine the most informative methods for assessing the functional capabilities of the patient;

– to master the specifics of assessing the functional state of patients with various diseases;

– to learn the methodology for conducting and assessing functional tests with physical activity;

– to learn how to assess the data of load tests, the results of the 6-minute test;

– to become familiar with functional load tests in the study of various body systems;

– it is necessary to be able to assess the readiness of patients for active participation in the rehabilitation process.

Requirements for the initial level of knowledge. To fully master the topic, you should review:

– from the course of normal physiology: physiology of muscle;

– activity;

– internal diseases: methods of functional diagnostics in cardiology and pulmonology;

– physiology and pathophysiology: the cardiovascular system.

Test questions from related disciplines:

1. Systems limiting physical performance.
2. Factors determining venous return of blood to the heart.
3. Reserves of oxygen supply to organs and tissues.
4. Modes of muscle contractions.
5. Classification of physical exercises depending on the mode of muscle work and mechanisms of energy supply of muscle activity.
6. Classifications of CHF.
7. Spirogram indicators.
8. Classification of respiratory failure.

Test questions on the topic of the lesson:

1. Classification of functional stress tests.
2. Tasks of stress testing.
3. Physical stress tests, general characteristics.

4. Indications and contraindications for muscle stress tests.
5. Methodology for conducting and evaluating the Martinet test.
6. Methodology for conducting and evaluating the 6-minute walk test.
7. Methodology for conducting the PWCmax test, test termination criteria, evaluation.
8. Transesophageal cardiac stimulation, test evaluation.
9. Tests with psychoemotional stress, practical application.
10. Vegetative tests
11. Breath-hold tests.
12. Pharmacological stress tests.

CLASSIFICATION OF FUNCTIONAL TESTS

All load tests can be classified by three criteria:

1. The nature of the impact:

– tests with physical load;
– tests with psycho-emotional load;
– tests with changes in the temperature of the external environment;
– tests with changes in atmospheric pressure;
– tests with the effect of linear or angular acceleration on the body;
– tests with changes in the composition of inhaled air;
– tests with breath holding;
– tests with food load;
– vegetative load tests;
– pharmacological tests.

2. The magnitude and intensity of the applied loads:

– maximal tests;
– submaximal tests;
– standard load tests.

Indications for stress tests:

1. Diagnostic:
a) confirmation of a suspected disease;
b) determination of the profile of an already known disease.
2. Evaluation of the effectiveness of treatment and rehabilitation.
3. Research work.

Contraindications for stress muscle testing.

1. Absolute:
– circulatory failure II-b and higher;
– acute myocardial infarction (within the first 5 days);
– unstable angina;

– heart rhythm disturbances (heart rate above 100 and below 40 beats per minute, frequent extrasystole.);

– blood pressure above 200/110;

– aneurysm of the heart, aorta, other vessels with initial blood pressure above 120/80 mm Hg;

– aortic dissection;

– intracardiac thrombosis;

– pulmonary embolism or pulmonary infarction (up to 3 months old);

– acute thrombophlebitis;

– acute myocarditis, endocarditis, pericarditis;

– critical aortic stenosis, other defects with intracardiac hemodynamic disturbances;

– clinically expressed persistent dysfunction of the central nervous system, organs of vision, liver, kidneys;

– frequent syncope;

– uncontrolled ventricular rhythm disturbances Lawn III–IV — frequent episodes of AV block grade II, AV block grade III;

– severe arthropathies, other extracardiac causes that prevent exercise;

– the patient did not sign informed consent for the test.

2. Relative:

– hemodynamically significant (non-critical) heart defects, including acquired;

– aneurysms of the heart, blood vessels;

– high-grade ventricular arrhythmias during therapy — severe uncontrolled supraventricular arrhythmias — episodes of stage II atrioventricular block;

– history of stroke or stroke with initial blood pressure above 120/80 mm Hg;

– pulmonary hypertension;

– severe diabetes mellitus;

– thyrotoxicosis, myxedema, severe obesity;

– psychosis or severe neurosis;

– severe varicose veins;

3. Conditions requiring special attention during testing: WPW syndrome, bundle branch block:

– presence of an implanted pacemaker with an imposed rate;

– intake of beta-blockers, cardiac glycosides, psychotropic drugs;

– anemia;

– neuromuscular, skeletal and joint disorders.

ENSURING THE SAFETY OF LOAD TESTS

When performing stress tests, it is important to ensure their safety. Even with the most scrupulous fulfillment of all requirements, complications may develop, including serious ones. The greatest danger is the risk of provoking severe coronary insufficiency and rhythm disturbances. An attack of angina that is relieved by nitroglycerin or passes when the load is stopped is not considered a complication of the test.

Stress tests may be performed by physicians who are fluent in electrocardiography and resuscitation. The test may be performed only if there is a full guarantee of emergency resuscitation; the room in which the test is performed must be equipped with a defibrillator, oral and tracheal airways, a hand-held mask respirator, a sterile tray with syringes and needles (including those for cardiac puncture), and a laryngoscope. In addition, the following medications are required to provide emergency care: narcotic (promedol) and non-narcotic analgesics in ampoules, nitroglycerin, mesaton (norepinephrine), prednisolone, lidocaine, novocainamide, inderal, strophanthin, lasix, sodium bicarbonate, 5 % glucose solution.

Correct patient selection, compliance with indications and contraindications for the test, ECG monitoring, and compliance with the test procedure generally guarantee the safety and effectiveness of physical exercise tests. The physician must obtain voluntary consent from the subject based on full information about the study in writing.

Electrocardiographic individual exercise tolerance test (PWC_{max})

This test assesses the patient's physical performance, determines the functional class of angina, the type of cardiovascular response to exercise, and exercise tolerance. A bicycle ergometer or treadmill, as well as an electrocardiograph with direct recording and a blood pressure monitor, are required for the test. The ECG is recorded with the patient seated (bicycle ergometer) or standing (treadmill).

On the day of the test, the patient should not smoke or take any medications. The test is performed no earlier than 2 hours after a meal.

The test termination criteria are:

1. Clinical:

– angina attack;

– systolic pressure decrease by more than 10 mmHg from baseline or no increase with increasing load;

– blood pressure increase above 220/130 mmHg;

– severe shortness of breath, asthma attack;

– dizziness, nausea, severe headache, slurred answers to questions, pallor, cyanosis;

– patient refusal to continue the test (fear or discomfort).

2. Electrocardiographic:

– horizontal, downward-sloping depression of the ST segment by 1 mm or more;

– a slow, upward ST depression with a 2-mm decrease in the j-point at Q-x > 50 % of the corresponding QT. The ischemic point (i-point) is typically determined on the ST segment. It lags behind the j-point by 0.06–0.08 seconds. The shift of the i-current relative to the isoline (h) is the main indicator of the test. A value of > 1 mm indicates the highest probability of ischemia (fig. 1);

– ST segment elevation by 1.5 mm. This is quite rare, mainly in patients who have had a myocardial infarction (30 %);

– ST depression during the recovery period (not recognized by all authors);

– frequent extrasystole (4 : 40), paroxysmal tachycardia, atrial fibrillation;

– development of atrioventricular and ventricular conduction disturbances;

– changes in the QRS complex.

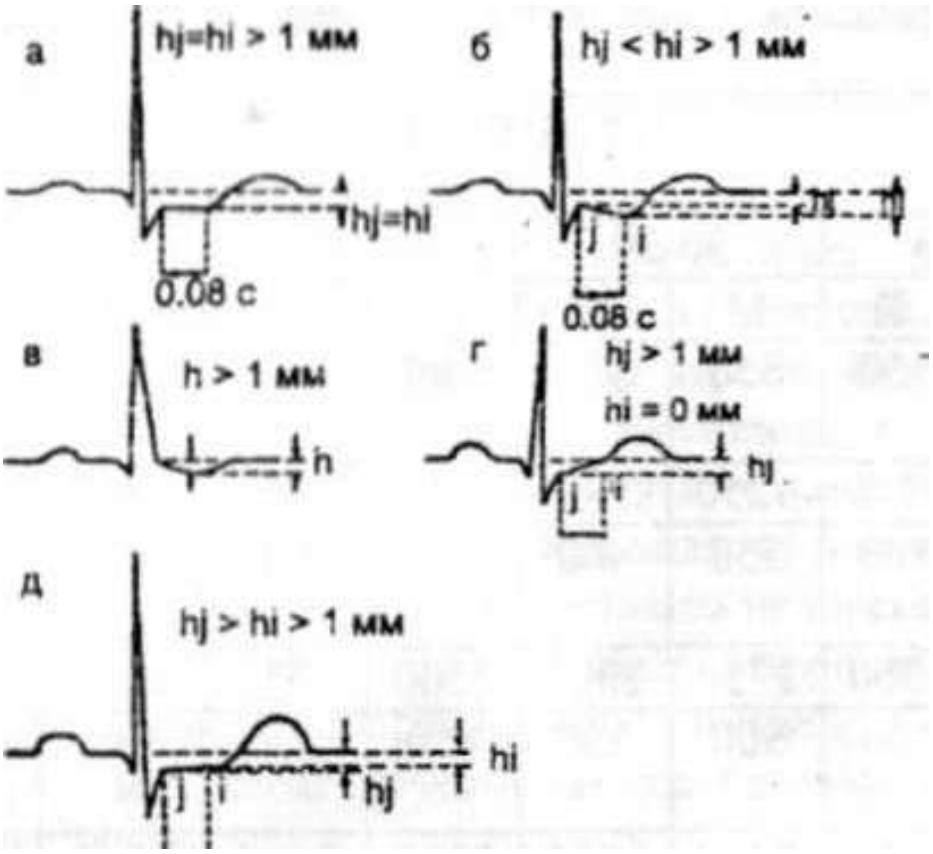


Fig. 1. Determination of the displacement point «j» and the ischemia point «i» for different types of ST segment displacement during functional tests

Including:

– QRS transition to QS;

– appearance of a Q wave absent before exercise, 0.03 sec wide and 1 mm or more in amplitude;

– decrease in Q amplitude by half or more with a baseline Q > 2 mm before exercise;

– widening of the Q wave or QS complex by 0.02 sec or more;

– decrease in R by 50 % or more with a baseline R = 5–10 mm, or by 25 % with a baseline R > 11 mm;

– increase in R by 100% or more with a baseline R = 5–10 mm and by 50 % with a baseline R > 11 mm;

– T-wave inversion or reversion (in diagnosed coronary artery disease).

The **test is stopped** when at least one of the listed signs appears.

The assessment of the exercise tolerance test results is the highest tolerable load at which one or more signs appear that indicate termination of the test. The load intensity is considered threshold if the duration of the final step of the gradually increasing exercise without signs of intolerance is at least 1 minute. Thus, the exercise tolerance indicator most often exceeds the threshold load level.

The intensity of the work performed is determined by the appearance of one of the above-mentioned signs of exercise intolerance.

The heart rate is determined at the moment signs of exercise intolerance appear. This heart rate is the maximum permissible rate for any physical activity, including household or industrial activities.

Myocardial oxygen consumption is determined during exercise and at rest.

The Robinson index, or double conduction (DC), is calculated as follows:

$$DP = \frac{BP \times HR}{100}.$$

The cardiac efficiency index (CI) is calculated as follows:

$$CI = DP : \text{threshold load power, W}.$$

In healthy people the indicator is 1.87 ± 0.6; in patients with coronary heart disease — 2.6–3.96.

With effective use of rehabilitation tools, the dynamics of the listed indicators are as follows:

1. Increased physical performance (the appearance of signs of exercise intolerance at higher intensity).

2. The appearance of signs of exercise intolerance at higher heart rates and higher conduction double-spin.

3. A decrease in conduction double-spin at rest and at a given intensity.

4. A decrease in the cardiac efficiency index at a given intensity.

Based on the results of tests performed for diagnostic purposes, a distinction is made between:

– negative test;
– inconclusive test;
– positive test;
– incomplete (non-informative) test.

Negative test — the subject has reached the age-related submaximal heart rate and has not developed any clinical or objective instrumental criteria for myocardial ischemia.

A negative test, but with peculiarities — the subject has reached the age-related heart rate and has a significant increase in blood pressure (230/120), infrequent extrasystole (less than 4 per 1 min), a collapse-like state, reversion or inversion of the T wave, severe shortness of breath, dizziness or headache, pain in the leg muscles.

Inconclusive test — when performed in a patient:

– developed pain typical of or resembling angina, but without ECG changes;
– observed horizontal ST segment depression of 0.5 mm or slowly ascending ST segment elevation of up to 1 mm;
– detected rhythm and conduction disturbances (frequent or polytopic extrasystoles, development of atrioventricular or intraventricular conduction disturbances, occurrence of paroxysms of supraventricular or ventricular tachycardia);
– decreased blood pressure by 20 mmHg or more from baseline at the peak of exercise.

Positive test — objective signs of myocardial ischemia appear with or without a simultaneous attack of angina pectoris.

Incomplete test — the subject did not reach the age-related submaximal heart rate, and did not develop either clinical or instrumental criteria of myocardial ischemia.

Based on the nature of changes in heart rate and blood pressure after functional tests, five reactions of the cardiovascular system are distinguished: ***normotonic, hypotonic, hypertonic, dystonic and stepwise type*** — with a stepwise increase in systolic pressure.

The normotonic type is characterized by a proportional increase in heart rate and systolic blood pressure; diastolic blood pressure does not change or changes slightly.

The hypotonic type is characterized by an inadequate increase in heart rate and a slight increase in systolic blood pressure; diastolic blood pressure does not change or changes slightly.

The hypertensive type is characterized by an increase in systolic blood pressure greater than 150 % of the baseline and/or diastolic blood pressure above 90 mmHg, along with a significant increase in heart rate.

The dystonic type is characterized by an increase in systolic blood pressure and a sharp drop in diastolic blood pressure, with a zero tone, the so-called «infinite» tone, being heard. The heart rate increases significantly.

The stepwise type is characterized by an increase in systolic blood pressure at 2–3 minutes of the recovery period higher than at 1 minute.

Treadmill test

Exercise testing protocols vary based on treadmill speed, treadmill incline, step duration, and changes in gait parameters (fig. 2). A number of standard, accepted protocols exist for different patient categories.

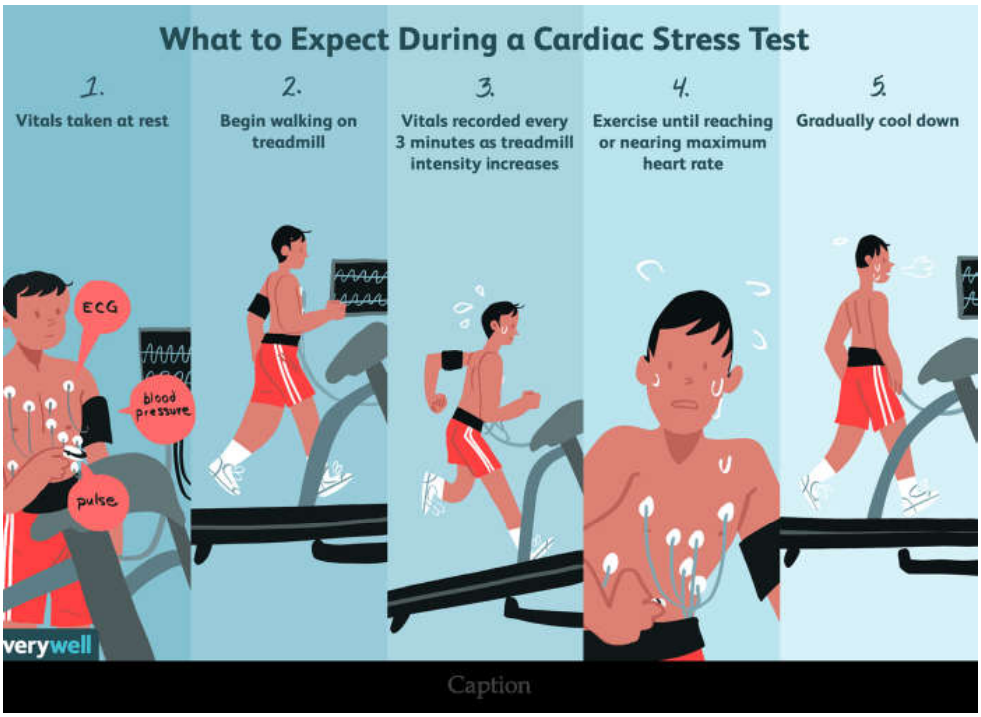


Fig. 2. Treadmill test

The most commonly used protocols are presented in Table 1.

For patients with expected good exercise tolerance, **the R. Bruce protocol**, with a rapid increase in treadmill speed and incline, is used. This protocol can be used in healthy individuals and patients under 75 years of age in the absence of significant comorbidities. If there is any doubt about successful completion of the test, including one of the relative contraindications to testing, it is better to use the **modified R. Bruce protocol (Mod Bruce)**. This protocol involves a slower increase in load on the initial steps. The **J. Naughton and B. Balke protocol** is used for testing patients with very low exercise tolerance and/or patients with circulatory failure.

Table 1

The most common protocols for the treadmill test

Step	Speed		Tilt angle (%)	Duration (min)
	mp/h	km/h		
the R. Bruce protocol				
1	1.7	2.7	10.0	3
2	2.5	4.0	12.0	3
3	3.4	5.4	14.0	3
4	4.2	6.7	16.0	3
5	5.0	8.0	18.0	3
6	5.5	8.8	20.0	3
7	6.0	9.6	22.0	3
the modified R. Bruce protocol (Mod Bruce)				
1	1.7	2.7	0.0	3
2	1.7	2.7	5.0	3
3	1.7	2.7	10.0	3
4	2.5	4.0	12.0	3
5	3.4	5.4	14.0	3
6	4.2	6.7	16.0	3
7	5.0	8.0	18.0	3
8	5.5	8.8	20.0	3
9	6.0	9.6	22.0	3

The total volume of physical activity performed is measured in metabolic units (MU). This is determined by how many times the patient's maximum workload increases their basal oxygen consumption. Basal oxygen consumption is conventionally considered equal to 3.5 ml/kg of body weight, i. e., 1 MU = 3.5 ml/(kg/min) of oxygen. The number of MUs, which characterize the functional capacity of the cardiovascular system, is directly related to VO2max.

Exercise stress testing allows for a fairly accurate prognosis and identification of patients at highest risk of complications. The worst prognosis is associated with patients who develop angina with a low degree of stress, accompanied by profound ST-segment depression and occurring at a low heart rate. Several indices reflect the prognostic value of exercise stress testing results. The Duke Treadmill Score (DTS) is considered the most appropriate. It is calculated using the formula:

$$\text{DTS} = \text{duration of exercise (minutes)} - (5 \times \text{ST shift (mm)}) - (4 \times \text{angina severity (score)}),$$

where angina severity is 0 — no angina during exercise, 1 — angina that does not prevent continued exercise, 2 — angina that limits continued exercise.

It is considered that a DTS value ≥ 5 indicates — a low risk, a DTS value 4–10 indicates — a moderate risk, and a DTS value ≤ 11 indicates — a high risk (table 2).

Table 2

Approximate ratios of units for determining exercise tolerance

MET	Watt	Tolerance
Up to 3.9	30–50	Low
4.0–6.9	50–75	Medium
Over 7.0	100–125	High
Over 8.0	Over 125	High

SPIROMETRY

Spirometry is a method for studying gas exchange and pulmonary ventilation during physical exertion. Aerobic energy is the primary source of energy for the body. The most comprehensive indicator of aerobic performance is the maximum amount of oxygen it can consume in one minute. The WHO recommends determining maximum oxygen consumption as one of the most reliable methods for assessing the performance of healthy and sick individuals. Oxygen consumption during muscular activity increases proportionally to its power. However, this relationship persists up to a certain level of work power. When the oxygen supply system's reserves are exhausted, oxygen consumption will not increase with further increases in workload. This level is the maximum oxygen consumption for a given individual. In real-life conditions, the circulatory system is the main limiting factor in oxygen transport during muscular work. One method for determining maximum oxygen consumption is spirometry. In rehabilitation practice, it allows for the most accurate assessment of the dynamics of a patient's condition during observation.

Indications for spirometry:

– differential diagnosis of dyspnea;

– determining the prognosis for acute and chronic coronary heart disease;

– stratifying cardiac risk before non-cardiac surgery;

– selecting an exercise regimen;

– additional assessment of CHF severity according to the Weber classification;

– determining exercise capacity and developing rehabilitation programs for patients with atrial fibrillation;

– differential diagnosis of left ventricular hypertrophy, for example, in athletes, from hypertrophic cardiomyopathy;

– determination of additional hemodynamic indications for surgical treatment of heart defects, taking into account exercise tolerance: for example,

patients with valvular defects with a VO max < 14 ml/min/kg require valve replacement;

– selection of patients for heart transplantation.

The generally accepted indication for heart transplantation is VO max < 10 ml/min/kg; the range of 10–14 ml/min/kg is considered a «gray zone» when other factors are taken into account (fig. 3).

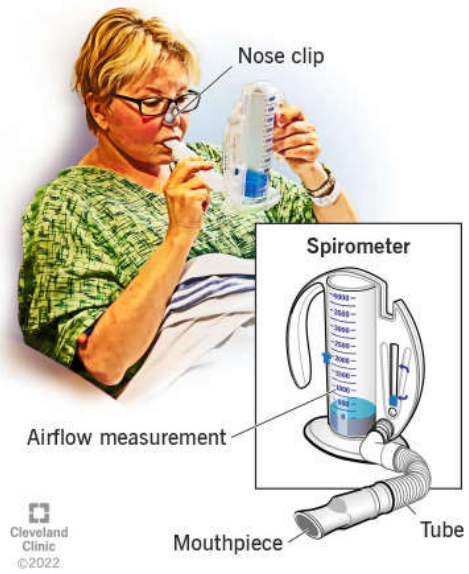


Fig. 3. Spirometry

To perform spirometry, the following equipment is required:

– a gas analyzer that automatically records oxygen consumption at rest and during exercise, as well as carbon dioxide production;

– a device for prescribing a measured load (cycle ergometer, stair climber, treadmill);

– an ECG recording device.

In the clinic, the spiroergometric test is performed using a continuously increasing load in stages. Each stage lasts 5 minutes, with an initial load of 25 W, and the load is subsequently increased by the same amount at each stage.

Test termination criteria:

– reaching maximum oxygen consumption (achieving a plateau on the oxygen consumption curve);

– the appearance of symptoms requiring termination of the exercise test (see the individual ECG exercise tolerance test). If these signs appear before reaching a plateau on the oxygen consumption curve, this is called symptom-limited VO2max.

Test results assessment:

1. Maximum achieved oxygen consumption (in L/min or ml/min/kg body weight, table 3, 4).

2. Maximum achieved «oxygen pulse» during exercise. Oxygen pulse is the amount of oxygen delivered to tissues during one heartbeat. For individuals aged 18–19, it is 17.1 ml/beat, 20–40 years — 16.8 ml/beat, 41–50 years — 15.6 ml/beat, 51–60 years — 13 ml/beat, and over 60 years — 11 ml/beat. For athletes, the maximum «oxygen pulse» averages 21.6 ml/beat.

3. Achievement of the following number of metabolic units (MU): in healthy, untrained middle-aged men, the number of MU is 10 or more, in athletes — 15–16 or more. In patients with FC IV coronary heart disease (CHD), the number is 2 MU, FC III — 2–3.9 MU, FC II — 4–6.9 MU, and FC I — 7 MU or more. The lower the number of MU in CHD patients, the worse the prognosis.

Table 3

Optimal values for maximum oxygen consumption for men, L/min

Age, years	Weight, kg										
	50	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
20–24	2,70	2,84	2,98	3,11	3,25	3,35	3,47	3,60	3,71	3,83	3,96
25–29	2,47	2,60	2,73	2,85	2,98	3,08	3,19	3,31	3,41	3,52	3,65
30–34	23	2,42	2,53	2,64	2,77	2,86	2,97	3,08	3,18	3,28	3,40
35–39	2,14	2,26	2,38	2,48	2,60	2,69	2,78	2,89	2,99	3,09	3,20
40–44	2,02	2,13	2,24	2,34	2,45	2,54	2,63	2,74	2,83	2,92	3,03
45–49	1,92	2,02	2,13	2,24	2,33	2,41	2,50	2,60	2,69	2,78	2,88
50–54	1,83	1,93	2,03	2,12	2,23	2,31	2,39	2,49	2,57	2,66	2,78

Table 4

Optimal values for maximum oxygen consumption for women, L/min

Age, years	Weight, kg									
	45	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**
20–24	2,32	2,46	2.58	2,71	2,82	2,94	3,05	3,15	ЗД6	3,36
25–29	2,15	2,27	2,39	2,50	2,61	2,72	2,82	2.92	3,01	3,13
30–34	2,01	2,13	2,24	2,34	2,44	2,54	2,63	2,72	2,81	2,90
35–39	1,90	2,01	2,11	2,20	2,30	2,39	2,48	2,57	2,65	2,73
40–44	1,81	1,91	2,01	2,10	2,19	2,28	3,36	2,45	2,52	2,60
45–49	1,72	1,81	1,90	1,99	2,08	2,16	2,24	2,32	2,39	2,47

With effective use of rehabilitation tools, the following dynamics of the listed indicators are observed:

- increase in maximum oxygen consumption during exercise;
- increase in the «oxygen pulse» during exercise;
- increase in the number of metabolic units during exercise?

6-MINUTE WALK TEST

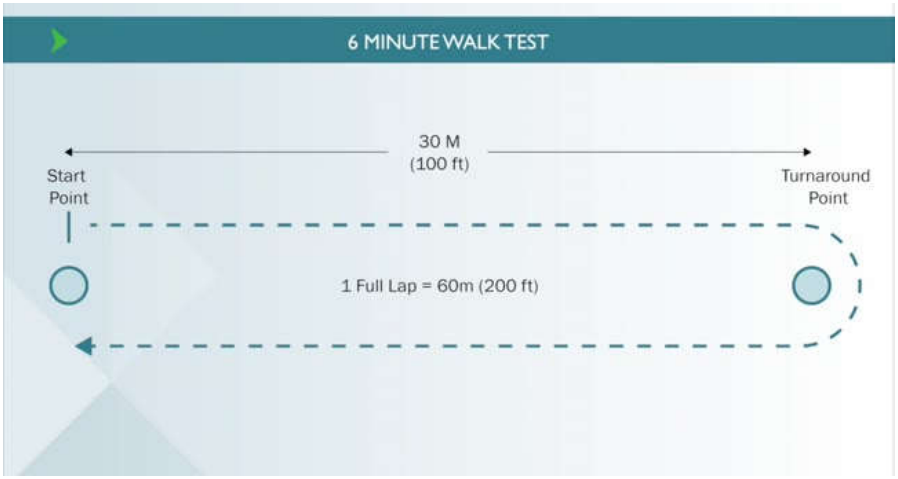
This test is used to assess the performance of patients with chronic lung diseases and to determine the functional class of CHF (table 5).

Table 5

The relationship between the functional class of chronic heart failure, 6-minute walk distance, and maximum oxygen consumption

FC by NYXA	6-minute walk distance, m	Oxygen consumption, ml/kg/min
0	more than 551	more than 22,1
1	426–550	18,1–22,0
2	301–425	14,1–18,0
3	151–300	10,1–14,0
4	less than 150	less than 10

Test procedure: performed in the morning on an empty stomach, the patient is required to walk at a reasonably fast pace the maximum distance along a corridor marked 1-meter apart for 6 minutes. If the patient stops to rest, the time spent doing so is included in the overall score (fig. 4).



	Mild (FEV_1 > 65% predicted) (n = 14)	Moderate (FEV_1 40–65% predicted) (n = 7)	Severe (FEV_1 < 40% predicted) (n = 10)	P*
Age (mean ± SD y)	20.4 ± 3.1	25.7 ± 6.1	26.2 ± 9.1	.056
Body mass index (mean ± SD kg/m²)	21.7 ± 2.2	19.5 ± 2.2	20.4 ± 1.6	.057
FEV_1 (mean ± SD % predicted)	86 ± 17	52 ± 6	32 ± 8	< .001
Shwachman-Kulczycki score (mean ± SD)	88.2 ± 8.0	72.1 ± 11.1	67.5 ± 11.6	< .001
6MWT Distance				
First 6MWT (mean ± SD m)	593.9 ± 65.2	594.0 ± 56.3	561.7 ± 81.5	.49
Second 6MWT (mean ± SD m)	597.6 ± 65.3	603.6 ± 83.2	569.9 ± 77.0	.57
CV (%)†	7.5	5.0	4.3	ND
Post-6MWT Heart Rate				
First 6MWT (mean ± SD beats/min)	129.1 ± 24.5	123.1 ± 17.9	135.4 ± 22.3	.54
Second 6MWT (mean ± SD beats/min)	134.7 ± 25.5	127.6 ± 14.8	138.5 ± 22.1	.62
CV (%)†	9.2	8.5	4.0	
Oxygen Desaturation‡				
First 6MWT (%)	0 ± 0.88	1.3 ± 1.9	6.8 ± 5.8	< .001
Second 6MWT (%)	-0.21 ± 0.58	0.57 ± 1.27	5.6 ± 5.3	< .001
CV (%)†	77	223	58	ND

Fig. 4. 6-minute walk test

The expected results for the 6-minute test are determined using the formulas of P. L. Enright and D. L. Sherrill (2001):

– for men – (7.57 × height in cm) – (5.02 × age) – (1.76 × weight in kg) – – 309;

– for women – (2.11 × height in cm) – (2.29 × age) – (5.78 × weight in kg) + + 667.

For individuals over 65 years of age, the recommended 6-minute walking distance is (P. L. Enright, 2003):

– men – 493 + (2.2 × height in cm) – (0.93 × weight in kg) – (5.3 × age) +17;

– women – 493 + (2.2 × height in cm) – (0.93 × weight in kg) – (5.3 × age).

ISOMETRIC LOAD TEST

In everyday life, people are required to perform not only dynamic but also static loads (lifting and carrying heavy objects, moving furniture, etc.). Therefore, during rehabilitation, it is necessary to incorporate these loads and determine their tolerance. Tests with manual and graduated isometric foot loads are typically performed.

Required equipment: electrocardiograph; hand dynamometer; device for static foot loads.

When performing a manual load test, the patient is initially asked to quickly squeeze a dynamometer with maximum force (IMGS — individual maximum grip strength). Then, to determine isometric exercise tolerance (in seconds), under ECG and blood pressure monitoring, loads of 50 and 75 % of IMGS are sequentially administered until signs of intolerance or arm fatigue appear. The rest period between the two load stages, until heart rate and blood pressure return to baseline, is 5 minutes or more.

The test is performed sequentially with one hand and the other.

The device for static foot loads consists of a frame with pedals connected to springs whose compression is calibrated in kg on a dynamometer, and a chair rigidly attached to the frame.

For test termination criteria, see the electrocardiographic exercise tolerance test.

With effective use of rehabilitation equipment, isometric strength and endurance increase. The «strength» indicator characterizes the final effect of the exercise in kilograms, while «endurance» measures the time during which static effort is maintained.

STRESS ELECTROCARDIOGRAPHY (TREADMILL, BICYCLE ERGOMETRY)

When myocardial ischemia occurs, local contractility disturbances precede ECG changes.

Stress echocardiography is used to detect myocardial ischemia and to assess myocardial viability in patients with CHF. The test is preferred when the ECG is initially abnormal (due to left ventricular hypertrophy, drug effects, or electrolyte disturbances).

The test's specificity is reduced by conduction disturbances and in patients who have had a myocardial infarction.

The criteria for a strongly positive test are as follows:

– left ventricular maximum ejection fraction of 35%;

– left ventricular ejection fraction increase during exercise by less than 5%;

– development of contractility abnormalities in several segments of the left ventricle;

– development of local contractility abnormalities in the left ventricle during exercise: 6.5 metabolic equivalents or heart rate < 120 beats per minute.

BREATH HOLD TESTS

The Stange test is the breath-holding time after a submaximal inhalation.

The Genchi test is the breath-holding time after a calm exhalation. The test is performed in a sitting position, without a preliminary warm-up. During the breath-hold, the subject pinches their nose with their fingers. The maximum possible breath-holding time is recorded. Healthy, untrained individuals hold their breath for 1 minute on inhalation and up to 30–40 seconds on exhalation.

With effective use of rehabilitation equipment, the maximum possible breath-holding time increases.

TEST WITH PSYCHOEMOTIONAL STRESS

The rationale for using psychoemotional stress tests is their enhanced cardiovascular activity in a person at rest. By simulating psychoemotional stress in patients with coronary artery disease, it is possible to induce an attack of angina with signs of myocardial ischemia and a hypertensive response. The cause of an attack of angina during psychoemotional stress is an increase in heart rate and blood pressure due to increased secretion of catecholamines, which leads to increased myocardial oxygen demand.

Contraindications for the test:

– acute cerebrovascular accident;
– hypertensive crisis;
– acute myocardial infarction;
– acute inflammatory diseases;
– uncorrectable visual impairment;
– frequent or clustered extrasystoles.

Conditions for performing the test: the test is performed in an isolated room with the windows closed, eliminating all extraneous stimuli. The test is performed in a sitting position, with blood pressure and a 12-lead ECG monitored.

There are many test options: mental arithmetic, sentence composition, and word composition. Two methods are recommended for the test. A disadvantage of this method is that the methods are not standardized.

A positive test is characterized by the appearance of signs of myocardial ischemia and dysfunction.

PHARMACOLOGICAL TESTS

Functional tests using pharmacological agents are divided into two groups:

– provocative;
– resolving.

Provocative pharmacological tests are essentially similar to tests involving physical and psychoemotional stress, as well as transesophageal cardiac stimulation. By disrupting the functional balance of the cardiovascular system, they provoke latent coronary insufficiency or help clarify the nature of coronary insufficiency.

Resolving pharmacological tests aim to correct the existing imbalance between regulatory systems and the affected organ. Consequently, under the influence of the resolving factor, the functions of the system being studied are temporarily eliminated or improved. Resolving pharmacological tests are safe, although they are inferior in diagnostic value to other tests.

In cardiology, reactive pharmacological tests include nitroglycerin, atropine, phentolamine (Reggetine), propranolol, potassium chloride, furosemide, and captopril tests. In pulmonology, tests with beta-mimetics and short-acting anticholinergics are used.

Various provocative tests can be used to assess the cardiovascular system:

1. Ergometrine (ergonovine) test. Ergometrine enhances alpha-adrenergic receptor stimulation and causes vasospasm.

This test is indicated for patients with clinical angina who do not show stenotic changes during coronary angiography.

The test is contraindicated:

- during the acute phase of myocardial infarction;
- in patients with a recent myocardial infarction;
- severe and multiple stenosing coronary atherosclerosis;
- severe cerebral atherosclerosis;
- heart failure;
- severe cardiac arrhythmias;
- arterial hypertension;
- severe aortic stenosis.

Test termination criteria: development of an angina attack, ischemic-type ECG changes, high-grade cardiac arrhythmia, and a sharp increase in blood pressure.

Evaluation criteria. The test is considered positive if the ST segment is shifted upward or downward from the isoelectric line by 1 mm or more.

If a pain attack occurs without electrocardiographic confirmation of myocardial ischemia, the test is considered inconclusive.

In patients with vasospastic angina, the ergometrine test provokes angina, accompanied by a significant elevation of the ST segment, leading to the appearance of a pattern resembling a «damage current» or a monophasic waveform in myocardial infarction.

2. Intracoronary acetylcholine injection test. Endothelial changes play a significant role in the pathogenesis of coronary atherosclerosis, with endothelial dysfunction occurring early in the atherosclerotic process or preceding it. Endothelial dysfunction is an early marker of atherosclerosis in coronary arteries that are normal on angiography.

With intact vascular endothelial function, acetylcholine stimulates the production of a special relaxation factor (nitric oxide NO), thereby causing an increase in vessel lumen. If the integrity or functional state of the endothelium is compromised, the arterial response to acetylcholine administration is altered.

The acetylcholine test is used to assess the functional state of the endothelium in patients with intact coronary arteries in the early stages of atherosclerosis.

The test is contraindicated in the following conditions:

- - the presence of any degree of stenosis of the left main coronary artery;
- - coronary artery stenosis (more than 50 % of the lumen).

Evaluation criteria:

The vessel's response is assessed when its diameter changes by 0.2 mm or more.

3. Dobutamine test. Dobutamine ECG test. Due to its beta-adrenergic stimulating effect, dobutamine increases heart rate, myocardial contractility, and, ultimately, cardiac output.

Indications:

– diagnosis of coronary heart disease;

– when a graded exercise test is not possible;

– a negative exercise test with clinical evidence of coronary heart disease in the patient;

– musculoskeletal disease.

Contraindications:

– acute myocardial infarction;

– unstable angina;

– severe cardiac arrhythmias (frequent, polytopic, grouped ventricular extrasystoles, paroxysmal ventricular tachycardia);

– circulatory failure stage IIB–III;

– cardiac or aortic aneurysm;

– aortic stenosis.

Test termination criteria and evaluation: similar to those for the exercise test.

4. Dobutamine stress echocardiography. Combining a dobutamine test with two-dimensional echocardiography enhances the diagnostic capabilities of the test.

Indications:

– assessment of chest pain of unclear etiology;

– assessment of the severity of coronary insufficiency in patients with established coronary artery disease;

– preoperative assessment of patients undergoing non-cardiac interventions;

– assessment of patients after coronary artery bypass grafting;

– myocardial assessment (stunned myocardium);

– risk stratification of patients after myocardial infarction;

– assessment of aortic stenosis with low cardiac output.

Contraindications:

– acute myocardial infarction (less than 4–10 days);

– unstable angina;

– suspected left main coronary artery disease;

– severe congestive heart failure;

– severe, life-threatening tachyarrhythmia;

– severe valvular stenosis;

– hypertrophic obstructive cardiomyopathy;

– acute pericarditis, myocarditis, endocarditis;

– known or suspected aortic dissection. Test termination criteria:

– angina;

– reaching a submaximal heart rate;

– development of severe ventricular or supraventricular extrasystole;

– hypotension;

– impaired or worsened left ventricular contractility (in two segments);

– ischemic depression of the ST segment.

Test evaluation criteria. Local contractility analysis is based on the conventional division of the left ventricle into 16 segments. Contractility of each segment is assessed in points:

– 1 — normal;

– 2 — hypokinesia (reduced);

– 3 — akinesia (absence of contractility);

– 4 — dyskinesia (passive displacement in the direction opposite to the normal movement of the segment during systole).

Assessment is based on the index of local contractility disorders of the left ventricle (the ratio of the total points to the number of segments assessed).

BRONCHOPROVOCATION TESTS

Provocative testing allows us to obtain transient bronchoconstriction and thus assess the presence and degree of airway hyperreactivity to various bronchoconstrictor irritants in patients with respiratory complaints.

With initially normal respiratory function, pharmacological tests (inhalation of histamine, methacholine, carbachol, and allergen solutions), tests with nonspecific provocateurs, and their combinations (e. g., physical exercise, hyperventilation, cold air inhalation, and hypo- and hypertonic aerosols) can be performed.

The most widely used test is with histamine, the main inflammatory mediator of bronchial asthma. Inhalation of histamine causes contraction of bronchial smooth muscle through direct stimulation of H1-histamine receptors, increasing vascular permeability.

After recording the initial respiratory function, a solvent (isotonic sodium chloride solution) is inhaled, followed by a histamine solution in successively increasing concentrations (from 0.0001 to 0.01 %). Re-recording of respiratory function using the flow-volume curve recording mode (pneumotachometry) is performed 30 and 90 seconds after each inhalation. The lowest values of the analyzed parameters, reflecting maximum bronchoconstriction at a given histamine dose, are used for analysis.

The test is considered positive if the forced expiratory volume in 1 second decreases by 20 % or more from the baseline value, or if the clinical equivalents of a positive test are the development of a typical attack of labored breathing and the appearance of scattered dry wheezing in the lungs. The test is considered positive regardless of the inhalation concentration of the solution that led to the diagnostic changes.

BRONCHOPROVOCATION TESTS WITH PHYSICAL EXERCISE

Functional exercise testing is highly specific for asthma. One indication for this test is the need to diagnose «exercise-induced asthma».

The exercise test is performed on a bicycle ergometer or treadmill at a temperature of 20 °C and humidity of approximately 40 %. The exercise intensity on the bicycle ergometer is 2.0 watts/kg of body weight for 6–8 minutes or until the generally accepted criteria for cessation of exercise are met. During the test, nasal breathing is blocked with a nose clip.

When evaluating the test results, spirometric readings are compared before exercise, immediately after exercise, and at 3, 6, 10, 15, and 20 minutes of the recovery period.

The test is considered ***positive*** if the forced expiratory volume in 1 second decreases by 10 percent or more compared to the forced expiratory volume in 1 second at rest.

ORTHOSTATIC TEST

An accessible research method is the orthostatic test. When shifting from a horizontal to a vertical position, blood flow to the right side of the heart decreases, with blood volume decreasing by approximately 20 % and cardiac output by 1–2.7 L/min. Increased sympathetic tone leads to increased heart rate and increased peripheral resistance.

Indications for the test:

- determining tolerance to sudden changes in body position;
- administering medications that affect blood redistribution;
- differential diagnosis of neurocirculatory disorders;
- studying autonomic regulation mechanisms;
- determining autonomic reactivity, etc.

There are no absolute contraindications to this test.

In healthy individuals, this test results in a decrease in systolic blood pressure (by 5–10 mmHg) and mean arterial pressure (by 3 mmHg), an increase in heart rate (by an average of 17 % of baseline), a decrease in stroke index (by an average of 20 % of baseline), and reductions in circulating blood volume, renal blood flow, and glomerular filtration. On the ECG, T-wave voltage decreases, the QT interval shortens, and the electrical position of the cardiac axis changes. A pathological reaction is expressed as a more pronounced change in hemodynamics, and an abnormal response may occur. In severe coronary insufficiency, ischemic depression of the ST segment may occur.

SELF-ASSESSMENT OF TOPIC COMPREHENSION

To assess their understanding of the topic, students are encouraged to answer test questions. Independent work with stress testing protocols and inpatient and outpatient medical records will help reinforce the acquired knowledge.

Situational tasks

Task 1. Patient K., 21, a student at the University of Economics.

Clinical Diagnosis: community-acquired polysegmental pneumonia in the left lower lobe, moderate severity. Severe bronchospastic syndrome, DN1.

At the time of examination, she complains of a cough with a small amount of mucous sputum throughout the day, shortness of breath with moderate physical exertion, and weakness.

Physical examination reveals a temperature of 37.7 °C. Skin color is normal. Breath sounds are bronchial in the left lower lobe, with scattered moist and dry wheezing. The boundaries of relative cardiac dullness are not shifted. Heart sounds are muffled, rhythm is regular. Pulse is 92 bpm, blood pressure is 105/70 mmHg.

Chest X-ray: polysegmental pneumonia in the left lower lobe.

Spirography: FEV1 — 55 %, FVC — 40 %, PEF — 71 %, MEF75 — 81 %, MEF50 — 103 %, MEF25 — 150 %, VC — 68 %.

ECG: sinus rhythm, moderate tachycardia.

Complete blood count: L — 8.3, p — 12, s — 52, l — 30, m — 6, ESR — 39 mm/hour.

Urinalysis: unremarkable.

1. Please indicate whether the patient has any contraindications for stress testing.

2. If there are no contraindications, select tests to determine the patient's functional status.

Task 2. Patient S., 42, child psychologist.

Clinical diagnosis: bronchial asthma, mixed form, moderate to severe persistent course, exacerbation. DN1.

At the time of examination, she complains of a cough with difficult-to-separate mucous sputum in the mornings, asthma attacks, mainly at night, 4–5 times a week, and shortness of breath with moderate exertion. She has had bronchial asthma for five years.

On physical examination, the temperature is 36.3 °C, moderate cyanosis of the lips and hands. The respiratory rate is 20 per minute. Percussion of the lungs reveals a tympanic sound. Breathing is harsh, with dry, scattered wheezing. The

boundaries of relative cardiac dullness are not shifted. Heart sounds are muffled, the rhythm is regular. Pulse is 88 beats per minute. BP — 130/80 mmHg.

Lung X-ray: no infiltrative shadows revealed. Emphysema

Diffuse pneumosclerosis.

Spirography: VC — 79 %, Tiffeneau test — 85 %, FVC — 70 %, FEVt — 64 %, PEF — 44 %, MEF75 — 59 %, MEF50 — 47 %, MEF25 — 39 %.

ECG: sinus rhythm. Signs of right ventricular strain. Complete blood count and urine analysis: normal.

1. Indicate whether the patient has any contraindications for stress testing.
2. If there are no contraindications, select tests to determine the patient's functional status.

Task 3. Patient S, 48, laboratory director.

Clinical diagnosis: coronary artery disease: angina, functional class II. Coronary artery atherosclerosis. Stage II hypertension, risk 3. CHF, functional class II (H1).

At the time of examination, the patient complained of pressing chest pain that occurred when walking up to 500 m and was relieved by nitroglycerin. Non-radiating chest pain occurred after psycho-emotional stress, as well as intermittent headaches, dizziness, fatigue, and decreased work capacity. He noted elevated blood pressure for 10 years; heart pain developed approximately three years ago.

Physical examination revealed that the patient was overweight. BMI 32. No edema. Respiratory rate 12 breaths per minute. Vesicular breathing, no wheezing. The boundaries of relative cardiac dullness were not shifted. The heart sounds are muffled, with a pronounced second heart sound over the aorta. The rhythm is regular. Pulse is 80 beats per minute, blood pressure is 170/95 mmHg. The liver is not palpable. ECG shows signs of left ventricular hypertrophy.

1. Indicate whether the patient has any contraindications for stress testing.
2. If there are no contraindications, select tests to determine the patient's functional status.

Task 4. Patient A., 57, retiree.

Clinical diagnosis: coronary artery disease: permanent atrial fibrillation. Coronary artery atherosclerosis. Stage II hypertension, risk 4. CHF IIFC (H1).

At the time of examination, she complains of shortness of breath with moderate physical exertion, palpitations, weakness, and unspecified heart pain. She notes an increase in blood pressure over the past 10 years. She has had persistent atrial fibrillation for about a year.

Physical examination reveals normal-colored skin. No edema. Respiratory rate is 16 breaths per minute. Vesicular breathing, no wheezing. The borders of relative cardiac dullness are as follows: right — in the 4th intercostal space, 4 cm

from the midline; left — in the 5th intercostal space along the medioclavicular muscle; in the 3rd intercostal space, the cardiac border is defined 2 cm medial to the medioclavicular muscle. Heart sounds are muffled, with the second sound accentuated over the aorta. The rhythm is irregular. Heart rate is 99 bpm, pulse rate is 93 bpm, blood pressure is 160/100 mmHg. The liver is at the costal margin.

1. Indicate whether the patient has any contraindications for stress testing.

2. If there are no contraindications, select tests to determine the patient's functional status.

Task 5. Patient V., 43, a mechanic.

Clinical diagnosis: coronary artery disease: stable angina, functional class II. Coronary atherosclerosis. Arterial hypertension stage II, risk 3. CHF functional class II (H1).

Physical performance at the beginning of the rehabilitation course: 75 W; at the end: 100 W.

Assess the patient's functional status over the course based on the test results.

Answers

Task 1. Yes.

Task 2. No: Breath-hold tests, 6-minute walk test.

Task 3. No: PWC max, VO2max.

Task 4. No: 6-minute walk test, breath-hold tests.

Task 5. Positive.

Tests

1. Functional tests assess:

a) health status;

b) functional capacity;

c) psychoemotional state and physical development.

2. Methods for assessing physical performance in patients with coronary heart disease include:

a) Stange and Genchi tests;

b) individual physical work capacity tolerance test (PWC MAX);

c) orthostatic test;

d) stress echocardiography with dobutamine.

3. A 6-minute test determines:

a) physical performance;

b) physical work capacity;

c) functional capacity;

d) FC of chronic heart failure.

4. The PWC 170 (W170) test means:

a) Work with a load on a bicycle ergometer;
b) Work with a load on a step;
c) Work performed in 170 seconds;
d) Workload at a heart rate of 170 bpm;
e) Workload on a bicycle ergometer.

5. The parameters required for calculating maximum oxygen consumption (L/min) using the indirect method after bicycle ergometry include:

a) first exercise power in kgm/min and heart rate;
b) second exercise power in kgm/min and heart rate;
c) pre-exercise heart rate and second exercise power in kgm/min;
d) maximum heart rate and maximum bicycle ergometry exercise power.

6. The clinical criteria for terminating the exercise test are:

a) reaching the maximum allowable heart rate;
b) angina attack;
c) drop in systolic blood pressure or increase more than 220 mmHg;
d) severe shortness of breath;
e) all of the above.

7. ECG — exercise test termination criteria are:

a) ST segment depression;
b) frequent extrasystoles, paroxysmal tachycardia, atrial fibrillation;
c) atrioventricular and intraventricular block;
d) marked increase in heart rate;
e) all of the above.

8. Subjective exercise test termination criteria are:

a) reaching submaximal heart rate, dizziness, headache, angina attack, refusal to continue the test, weakness;
b) dizziness, headache, angina attack, refusal to continue the test, weakness;
c) reaching submaximal heart rate, dizziness, headache, angina attack, weakness.

9. The rational type of response to physical activity includes:

a) hypotonic;
b) hypertonic;
c) stepwise;
d) normotonic;
e) dystonic.

10. The normotonic type of response to physical activity is characterized by:

a) an increase in heart rate by 80–100 % of baseline, an increase in systolic blood pressure more than 150 % of baseline, an increase in diastolic blood pressure, an increase in spherical pressure;

b) an increase in heart rate by 100–150 % of baseline, a slight increase in systolic blood pressure, an insignificant change in diastolic blood pressure and spherical pressure;

c) an increase in heart rate by 100–150 % of baseline, an increase in systolic blood pressure, a decrease in diastolic blood pressure, up to the appearance of an infinite tone;

d) an increase in heart rate by 50–80 % of baseline, an increase in systolic blood pressure up to 150 % of baseline, an insignificant change in diastolic blood pressure, an increase in spherical pressure.

11. The hypertensive type of response to physical exercise is characterized by:

a) an increase in heart rate by 50–80 % of baseline, an increase in systolic blood pressure up to 150 % of baseline, an insignificant change in diastolic blood pressure, and an increase in spherical pressure;

b) an increase in heart rate by 80–100 % of baseline, an increase in systolic blood pressure more than 150 % of baseline, an increase in diastolic blood pressure, and an increase in spherical pressure;

c) an increase in heart rate by 100–150 % of baseline, an insignificant increase in systolic blood pressure, and an insignificant change in diastolic blood pressure and spherical pressure;

d) an increase in heart rate by 100–150 % of baseline, an increase in systolic blood pressure, and a decrease in diastolic blood pressure, up to the appearance of an infinite tone.

12. The hypotonic type of response to physical exercise is characterized by:

a) an increase in heart rate by 80–100 % of baseline, an increase in systolic blood pressure more than 150 % of baseline. baseline, increased DBP, increased PP;

b) increased HR by 100–150 % of baseline, slight increase in SBP, slight change in DBP and PP;

c) increased HR by 100–150 % of baseline, increased SBP, decrease in DBP, up to the appearance of an infinite tone;

d) increased HR by 50–80 % of baseline, increased SBP up to 150 % of baseline, slight change in DBP, increased PP.

13. The dystonic type of response to physical activity is characterized by:

a) increased HR by 80–100 % of baseline, increased SBP more than 150 % of baseline, increased DBP, increased PP;

b) increased HR by 100–150 % of baseline, slight increase in SBP, slight change in DBP and PP;

c) an increase in heart rate by 100–150 % of baseline, an increase in systolic blood pressure, a decrease in diastolic blood pressure, up to the appearance of an infinite tone;

d) an increase in heart rate by 50–80 % of baseline, an increase in systolic blood pressure up to 150 % of baseline, a slight change in diastolic blood pressure, and an increase in PP.

Answers: 1 — b, **2** — b, **3** — d, **4** — d, **5** — d, **6** — e, **7** — e, **8** — b, **9** — d, **10** — d, **11** — b, **12** — b, **13** — c.

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