Electrocardiographic exercise testing in adults: performance and interpretation. An expert opinion of the Polish Cardiac Society Working Group on Cardiac Rehabilitation and Exercise Physiology

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A b s t r a c t

Electrocardiographic (ECG) exercise stress test has been a major diagnostic test in cardiology for several decades. Ongoing technological advances that have led to a wide use of imaging techniques and development of new guidelines have called for a revised and updated approach to the technique and interpretation of the ECG exercise testing. The present document outlines an expert opinion of the Polish Cardiac Society Working Group on Cardiac Rehabilitation and Exercise Physiology regarding the performance and interpretation of ECG exercise testing in adults. We discussed technical requirements and necessary equipment for the exercise testing laboratory as well as healthcare personnel competencies necessary to supervise ECG exercise testing and fully interpret test findings. Broad indications for ECG exercise testing include diagnostic assessment of coronary artery disease (CAD), including pre-test probability of CAD, evaluation of functional disease severity and risk stratification in patients with established CAD, assessment of response to treatment, evaluation of exercise-related symptoms and exercise capacity, patient evaluation before exercise training/cardiac rehabilitation, and risk stratification prior to non-cardiac surgery. ECG exercise testing is safe if indications and contraindications are observed, testing is appropriately monitored, and indications for test termination are clearly established. The exercise protocol should be adjusted to the expected exercise capacity of a patient so as to limit the duration of exercise to 8–12 min. Clinical, haemodynamic, and ECG response to exercise is evaluated during the test. The test report should include information about the exercise protocol used, reason for test termination, perceived exertion, presence/severity of anginal symptoms, peak exercise capacity or tolerated workload in relation to the predicted exercise capacity, heart rate response, and the presence or absence of ST-T changes. The test report should conclude with a summary including clinical and ECG assessment.

Key words: electrocardiography, exercise stress testing

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INTRODUCTION

Electrocardiographic (ECG) exercise stress test has been a major diagnostic test in cardiology for several decades. Ongoing technological advances and development of new guidelines have called for a revised and updated approach to the technique and interpretation of the ECG exercise testing. The present document outlines an expert opinion of the Polish Cardiac Society Working Group on Cardiac Rehabilitation and Exercise Physiology regarding the performance and interpretation of ECG exercise testing in adults. The present expert opinion was designed to be concise and brief, and a detailed discussion of issues relevant to exercise testing can be found in our previous statement published in 2016 [1]. The present expert opinion was developed based on that publication, the European Society of Cardiology (ESC) guidelines [2], and statements and guidelines of the American cardiac societies (American College of Cardiology [ACC] and American Heart Association [AHA]) [3–6].

TECHNICAL REQUIREMENTS FOR EXERCISE STRESS TESTS
Personnel

The personnel of the exercise testing laboratory should consist of medically-trained individuals experienced in exercise testing. The minimum required personnel includes one physician and one additional staff member (nurse, technician, or physiotherapist). Testing should be supervised by a physician experienced in exercise testing. To achieve the required expertise, it is necessary to perform and interpret at least 50 exercise tests under supervision. To maintain competence, it is necessary to perform at least 25 exercise tests a year [6].

Skills needed for the performance and interpretation of the electrocardiographic exercise testing [6]

Skills needed to supervise an exercise tests:
— Knowledge of indications for exercise testing
— Knowledge of contraindications to and risks of testing
— Knowledge of various exercise protocols and indications for their use
— Knowledge of preparation for exercise testing (skin preparation, lead placement)
— Knowledge of end points of exercise testing and indications to terminate an exercise test
— Knowledge of basic exercise physiology, including haemodynamic response to exercise
— Knowledge of cardiac arrhythmias and the ability to recognise and treat serious arrhythmias
— Knowledge of the ECG evidence of myocardial ischaemia
— Knowledge of cardiovascular drugs and their effect on exercise performance, haemodynamic parameters, and the ECG

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— Knowledge of the effects of age and disease on haemodynamic and ECG responses to exercise
— Ability to recognise and treat complications of exercise testing
— Ability to perform cardiovascular resuscitation

Additional skills needed to fully interpret exercise tests:
— Ability to interpret ECG findings
— Knowledge of sensitivity, specificity, and diagnostic accuracy of exercise testing in different patient populations
— Knowledge of the prognostic value of exercise testing
— Knowledge of and ability to apply Bayes' theorem to interpret exercise test results
— Knowledge of conditions and circumstances that can result in false-positive or false-negative test results
— Knowledge of the concept of metabolic equivalent (MET) and estimation of the recommended exercise intensity based on the findings of an exercise test
— Knowledge of alternative and supplementary diagnostic procedures

Equipment for the exercise testing laboratory
Testing room

The exercise testing room should be large enough to allow an unobstructed access to the patient, including room for cardiopulmonary resuscitation and arrangement of patient transport in emergency situations, if necessary. The laboratory should be well lighted and well ventilated, with controlled temperature and humidity. The recommended room temperature is 20°C to 22°C, with the recommended humidity of 50%.

A scale of perceived exertion (6–20 or 0–10 Borg scale) (Table 1) and a 1–4 scale for the severity of angina and dyspnoea (Table 2) [4, 7, 8] should be placed in clear view of the patient and personnel. The laboratory should be equipped with a readily available examination table, so the patient can be rested in a supine position after the testing if necessary.

The exercise testing laboratory should be equipped with an exercise testing system, device for blood pressure measurement, examination table, pulse oximeter (optionally), and equipment for cardiopulmonary resuscitation.

Exercise testing system

The exercise testing system, based on a treadmill or cycle ergometer, should be connected to a control module. The optimal solution is to have both treadmill and cycle ergometer available. A standard exercise testing laboratory does not have to be equipped with an arm ergometer.

It is recommended to use computer software for exercise testing that allows continuous monitoring of 12-lead ECG to evaluate ST-T changes, and it is acceptable to choose several leads to monitor cardiac rhythm. The system ought to allow data archiving.

Table 1. Rating of perceived exertion — Borg scale and modified Borg scale

Borg scale		Modified Borg scale	
6		0	Nothing at all
7	Very, very light	0.5	Very, very weak
8		1	Very weak
9	Very light	2	Weak
10		3	Moderate
11	Fairly light	4	Somewhat strong
12		5	Strong
13	Somewhat hard	6	
14		7	Very strong
15	Hard	8	
16		9	Very, very strong (almost maximum)
17	Very hard	10	Maximum
18			
19	Very, very hard		
20	Maximum		

Table 2. Severity scales of angina and dyspnoea

Angina severity scale	
1 +	Onset of discomfort
2 +	Moderate, bothersome
3 +	Moderately severe
4 +	Very severe
Dyspnoea severity scale	
1 +	Mild, noticeable to patient but not observer
2 +	Mild, noticeable to observer
3 +	Moderate difficulty but can continue
4 +	Severe difficulty, patient cannot continue

Equipment for blood pressure measurement

A device for blood pressure measurement should allow to select cuff size. Because of the interferences related to the functioning of the exercise testing system, devices for manual pressure measurement are preferred. It is recommended to choose an appropriate cuff size depending on the arm circumference. Cuffs should be disinfected after each use.

Resuscitation trolley

A resuscitation trolley should be located in a place that is clearly visible and easily accessible. The personnel should be trained in cardiopulmonary resuscitation, and a system of regular training and drills is recommended. A protocol for cardiopulmonary resuscitation should be clearly defined and established in accordance with the European Resuscitation Council guidelines [9, 10]. A telephone with the number to be dialled to activate the resuscitation team (if such is available in a given institution) should be located in the laboratory or nearby. The laboratory should be equipped with a portable automated external defibrillator. Proper functioning of the device should be regularly checked by responsible staff members. The minimal set of medications should include syringes, intravenous infusion sets, infusion fluids (0.9% saline, 5% dextrose), sublingual nitroglycerin, atropine, lidocaine, adenosine, adrenaline, amiodarone, dopamine, intravenous metoprolol, and acetylsalicylic acid (soluble 300 mg tablets).

INDICATIONS AND CONTRAINDICATIONS TO ELECTROCARDIOGRAPHIC EXERCISE TESTING

Indications and contraindications to electrocardiographic exercise testing should be always observed.

Indications for electrocardiographic exercise testing

Indications for electrocardiographic exercise testing [1, 2, 3]:
— As the initial test for establishing a diagnosis of stable coronary artery disease (CAD) in patients with symptoms of angina and intermediate pre-test probability of CAD (15%–65%) (Table 3)
— Evaluation of the functional severity of CAD (evaluation of coronary reserve)
— Risk stratification in patients with established CAD
— Evaluation of exercise capacity and exercise tolerance
— Patient evaluation prior to physical exercise/training
— Risk stratification prior to non-cardiac surgery (according to the ESC/ESA guidelines on non-cardiac surgery) [11]
— Evaluation of response to treatment (physical training, drug therapy, pacing)
— Assessment of exercise-induced symptoms (hypertensive response, chronotropic response, cardiac arrhythmias, symptoms related to valvular heart disease or cardiomyopathies)

Contraindications to electrocardiographic exercise testing

Absolute contraindications (according to AHA) [3]:
— Acute myocardial infarction (first two days)
— Unstable angina
— Uncontrolled cardiac arrhythmia with significant symptoms or haemodynamic compromise
— Active infective endocarditis
— Symptomatic severe aortic stenosis
— Decompensated heart failure
— Acute pulmonary embolism, pulmonary infarction, or deep vein thrombosis
— Acute myocarditis or pericarditis
— Acute aortic dissection
— Physical disability that precludes safe testing

Table 3. Pre-test probability of coronary artery disease in stable patients with chest pain according to the European Society of Cardiology

Age [years]	Typical angina		Atypical angina		Nonanginal pain	
	Men	Women	Men	Women	Men	Women
30–39	59	28	29	10	18	5
40–49	69	37	38	14	25	8
50–59	77	47	49	20	34	12
60–69	84	58	59	28	44	17
70–79	89	68	69	37	54	24
> 80	93	76	78	47	65	32

The table shows estimated probability (%) of the presence of a significant coronary artery obstruction.

Relative contraindications (testing may be performed with special caution when the expected benefits outweigh the risk) (according to AHA) [3]:

— Left main coronary artery stenosis

— Moderate to severe aortic stenosis with uncertain relation to symptoms

— Tachyarrhythmias with uncontrolled ventricular rate

— Acquired advanced or complete atrioventricular block

— Hypertrophic cardiomyopathy with significant resting outflow tract obstruction

— Recent stroke or transient ischaemic attack

— Mental impairment with limited ability to cooperate

— Hypertension with resting pressure > 200/110 mmHg

— Uncorrected medical conditions, such as significant anaemia, significant electrolyte imbalances, or hyperthyroidism

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ECG changes that are a contraindication to the evaluation of CAD with ECG exercise testing [2, 5]:

— Persistent left bundle branch block

— Preexcitation syndromes

— Ventricular pacing

— Baseline ST depression ≥ 0.1 mV

— Digitalis-induced ST changes

PREPARATION FOR TESTING
Purpose of the test

The purpose of the test should be indicated in the referral form or defined prior to the initiation of testing and noted in the test documentation.

Patient medical history

Before the testing, a short history should be taken regarding patient's major complaints and physical capacity, with particular attention to symptoms within the last week. Daily physical activity of the patient should be documented. The test documentation should include names and doses of cardiovascular medications taken by the patient, including the time when the last drug dose was administered on the day of the testing. Conditions of potential importance for the conduct and result of the testing (e.g. orthopaedic and neurological disorders, anginal symptoms, symptoms of heart failure, mental disorders such as depression or anxiety) should be documented.

Patient data

Before the test, a consecutive test number should be assigned and patient data should be entered to the system, including first name, family name, sex, date of birth, height, weight, patient contact data (address, telephone number), and the name of the referring physician.

Stress testing protocol

The test protocol should be selected according to the patient characteristics. Protocols with more intensive workload increments should be selected for young and fit patients, and protocols with more modest increases in workload between stages should be selected for older patients with reduced exercise capacity and concomitant conditions. The stress protocol should be chosen in such a way that a maximum/target exertion is reached between 8 and 12 min of the exercise stage.

Maximum heart rate and chronotropic response

The recommended formula for maximum heart rate is: 220 – age (in years) [12]. The maximum heart rate is used to calculate the target heart rate that is diagnostic for the diagnosis of CAD and is set at 85% of the maximum heart rate.

The chronotropic response is evaluated based on the percentage of the maximum heart rate at peak exercise, heart rate reserve, and the chronotropic index.

Heart rate reserve and the chronotropic index are calculated using the following formulas:

— Heart rate reserve = maximum heart rate – resting heart rate

— Chronotropic index = [(peak heart rate during exercise – resting heart rate) / heart rate reserve] × 100%

Predicted, relative, and expected exercise capacity

Predicted exercise capacity is defined based on studies in healthy population using regression equations adjusted for age and sex.

Formulas recommended for calculating the predicted exercise capacity (in MET):

For men [13]: MET = 18 – (0.15 × age)

For women [14]: MET = 14.7 – (0.13 × age)

Calculated predicted exercise capacity (in MET) is shown in Table 4.

It is recommended to determine relative exercise capacity by calculating the ratio of the achieved peak value in METs to the predicted exercise capacity.

Relative exercise capacity is expressed as a percentage value according to the formula:

Relative exercise capacity (%) = 100 × exercise capacity in MET at peak exercise/predicted exercise capacity

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Predicted workload (PWR) for cycle ergometer (in watts [W]) can be calculated using the following formulas [15]:

For men: W = (20.4 × H – 8.74 × A – 1909) × 0.1634

For women: W = (20.4 × H — 8.74 × A – 288 – 1909) × 0.1634

H — height [cm]

A — age [years]

Relative peak tolerated workload is expressed as a percentage value according to the formula:

% PWR = 100 × peak tolerated workload in W / PWR

Expected exercise capacity is defined as the individual exercise tolerance estimated prior to the testing based on age, sex, clinical condition, and the usual physical activity of a patient. For patients with average exercise tolerance, the expected exercise capacity is equal to the predicted exercise capacity.

As individualisation of the test protocol is recommended to achieve peak exertion at 8–12 min of the exercise stage of the test, it is recommended to estimate the expected exercise capacity for a given patient and then select a test protocol that enables to achieve this level of workload within the desired time frame. There are algorithms to estimate the expected peak exercise capacity based on the usual physical activity of the subject, but their discussion is beyond the scope of the present document [16, 17].

Criteria for inappropriate clinical, haemodynamic, and ECG response

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Criteria for inappropriate clinical and haemodynamic response [1, 2, 3, 8, 18]:

— Reduced exercise tolerance (< 85% of the predicted value for age and sex) [18]

— Occurrence of exercise-induced chest pain

— Inappropriate systolic blood pressure response:
  • excessive increase (absolute value, > 210 mmHg in men, > 190 mmHg in women) [3]
  • inadequately low increase (≤ 44 mmHg in the general population, inability to achieve 140 mmHg or increase < 30 mmHg in patients with a history of myocardial infarction, < 20 mmHg in patients with hypertrophic cardiomyopathy or aortic stenosis) [1]
  • exercise-induced hypotension (drop ≥ 10 mmHg during exercise following an initial increase) [3]

— Inappropriate diastolic blood pressure response (increase > 10 mmHg compared to baseline or absolute value > 90 mmHg) [3]

— Inappropriate chronotropic response (heart rate at peak exercise < 85% of the maximum heart rate, chronotropic index < 80% [≤ 62% in subjects treated with β-blockers])

— Inappropriate heart rate reduction during recovery (≤ 12 bpm during the first minute)

Criteria for inappropriate ECG response [1, 3, 8]:

— J point depression ≥ 0.1 mV and horizontal/downsloping ST depression (at 80 ms after the J point, 60 ms with heart rate > 130 bpm)

— J point elevation ≥ 0.1 mV and ST elevation ≥ 0.1 mV (at 60 ms after the J point) in leads without pathological Q wave

— J point depression ≥ 0.1 mV and upsloping ST depression (a borderline criterion)

ST depression should be measured relative to the isoelectric line (PR segment) or relative to the baseline depression if the J point is mildly depressed (< 0.1 mV) at baseline in relation to the PR segment, and ST elevation should be measured relative to the baseline.

Exercise testing in patients with an implanted pacemaker, cardioverter-defibrillator, or cardiac resynchronisation therapy device

Electrocardiographic exercise testing may be safely performed in patients with an implanted pacemaker, cardioverter-defibrillator, or cardiac resynchronisation therapy device if the following limitations are considered [1, 3]:

Table 4. Predicted exercise capacity in relation to age in men and women (in metabolic equivalent [MET])

Age	Men*	Women**	Age	Men*	Women**
20	15.0	12.1	51	10.4	8.1
21	14.9	12.0	52	10.2	7.9
22	14.7	11.8	53	10.1	7.8
23	14.6	11.7	54	9.9	7.7
24	14.4	11.6	55	9.8	7.6
25	14.3	11.5	56	9.6	7.4
26	14.1	11.3	57	9.5	7.3
27	14.0	11.2	58	9.3	7.2
28	13.8	11.1	59	9.2	7.0
29	13.7	10.9	60	9.0	6.9
30	13.5	10.8	61	8.9	6.8
31	13.4	10.7	62	8.7	6.6
32	13.2	10.5	63	8.6	6.5
33	13.1	10.4	64	8.4	6.4
34	12.9	10.3	65	8.3	6.3
35	12.8	10.2	66	8.1	6.1
36	12.6	10.0	67	8.0	6.0
37	12.5	9.9	68	7.8	5.9
38	12.3	9.8	69	7.7	5.7
39	12.2	9.6	70	7.5	5.6
40	12.0	9.5	71	7.4	5.5
41	11.9	9.4	72	7.2	5.3
42	11.7	9.2	73	7.1	5.2
43	11.6	9.1	74	6.9	5.1
44	11.4	9.0	75	6.8	5.0
45	11.3	8.9	76	6.6	4.8
46	11.1	8.7	77	6.5	4.7
47	11.0	8.6	78	6.3	4.6
48	10.8	8.5	79	6.2	4.4
49	10.7	8.3	80	6.0	4.3
50	10.5	8.2			

*Values for men calculated using the formula: $MET = 18 - (0.15 \times age)$, **Values for women calculated using the formula: $MET = 14.7 - (0.13 \times age)$

— prior to the testing, it is important to know the type of the pacemaker, pacing mode, and rate-response function settings;

— heart rate response depends on the chronotropic competence and the mode of pacing;

— with fixed pacing rate, the testing should be guided by patient exertion and percentage predicted workload;

— exercise in a patient with an implanted cardioverter-defibrillator should be limited so as to increase the heart rate to 10–15 bpm below the arrhythmia detection threshold (optionally, the arrhythmia detection threshold may be temporarily set above the maximum heart rate, or the antiarrhythmic therapy functions may be disabled for testing);

— evaluation of ischaemia is not feasible in patients with ventricular pacing;

— loss of cardiac resynchronisation pacing during the testing is an indication to terminate the test.

PATIENT PREPARATION FOR THE TESTING
Informing the patient about the test and obtaining written consent

Before the testing, the patient should be informed about the purpose and conduct of the test. Information about the test may be provided in writing or verbally. It is necessary to obtain a written consent for the test [1]. A sample consent form is shown in Table 5.

Table 5. Exercise testing consent form

NAME OF THE LABORATORY

ELECTROCARDIOGRAPHIC EXERCISE TESTING
INFORMED CONSENT FORM

PATIENT NAME AND SURNAME: ……………….....................................………   ……………………....................................………….

PERSONAL IDENTIFICATION (PESEL) NUMBER

Purpose of the testing

Electrocardiographic exercise testing is performed to evaluate exercise capacity, diagnose coronary artery disease, evaluate coronary reserve, or assess response to treatment.

Description of the testing

The testing will be performed on a treadmill or a cycle ergometer under physician supervision. Single-use leads will be placed on the torso and connected to a computer that analyses the electrocardiogram. You will be asked to walk or cycle at a given rate, with the workload adjusted to your capabilities. The workload will be gradually increased by rising the treadmill speed and slope (or increasing pedal resistance of the cycle ergometer). When the desired parameters are reached, the physician will terminate the test. The test may also be terminated at any time at your request or if worrisome symptoms develop. During the test, the electrocardiogram will be monitored continuously, and blood pressure will be measured periodically, every 2–3 minutes. Exercise will be followed by several minutes of recovery, during which the electrocardiogram will be monitored and blood pressure will be measured.

Information that should be disclosed to the healthcare personnel carrying out the test

Any new symptoms that developed during the last few days (common cold, fever, chest pain etc.) should be reported before the test. Close cooperation with the healthcare personnel carrying out the test is necessary to achieve a meaningful test result. During the test, the patient should immediately report any complaints (pain, shortness of breath, dizziness, tinnitus etc.). However, it should be remembered that some degree of fatigue is normal during exercise testing and is not a reason for terminating the test. Premature termination of the test precludes obtaining the information expected by the referring physician.

Possible complications/risks

Exercise testing is a safe investigation but very rare cases of myocardial infarction and death have been reported. The most common complications include prolonged chest pain, arrhythmia, dizziness, fall in blood pressure, and leg pain. Some people may develop contact skin allergy in the areas of lead attachment. Fatigue may last up to several hours after the testing.

PATIENT STATEMENT

— I have got acquainted with the description of the proposed testing, its purpose, and possible risks that may arise due to the testing.

— I hereby declare that I have obtained satisfactory answers to my questions and I have fully understood the presented information.

I HEREBY GIVE AN INFORMED AND VOLUNTARY CONSENT TO THE PROPOSED TESTING

………………………………………………………………………………………...………

Date   *Legible signature of the patient/legal guardian*

I DO NOT GIVE CONSENT TO THE PROPOSED TESTING

I have been informed about possible negative consequences of this decision for my health and life.

………………………………………………………………………………………...………

Date   *Legible signature of the patient/legal guardian*

Physician taking the consent

………………………………………………………………………………………...………

Date   *Signature and stamp*

Patient preparation

The patient should come in for the test about 3 h after a light meal, wearing comfortable, loose clothing and sport-type shoes that allow comfortable walking on the treadmill or cycling on the ergometer. The patient should avoid intensive exertion and refrain from drinking strong coffee, tea or energy drinks and smoking tobacco for 6 h before the testing.

When exercise testing is performed for diagnostic purposes, it may be considered to withhold symptom-masking medications (e.g., β-blockers, nitrates) before the test. It is not recommended to withhold usual medications if the testing is performed to evaluate treatment response or exercise capacity.

Skin preparation and lead placement

Careful skin preparation before the testing is of key importance for the quality of the obtained ECG signal. A special paste should be used to remove superficial oils and the outermost epidermal layer. Excessive body hair in the areas of electrode application should be first shaved off. Adequate skin preparation should reduce skin resistance to 5000 ohm or less. The Mason-Likar lead system should be used for lead placement on the torso [19].

CONDUCT OF THE EXERCISE STRESS TESTING
Exercise testing stages

The test protocol should include a warm-up stage (2–3 min), the exercise stage with graded (every 2–3 min) or continuous increase in workload (optimal overall duration of 8–12 min), and a recovery period (5 min or until resolution of the ECG changes and/or clinical symptoms).

Test protocols

Graded or ramp protocols are used for testing at an increasing workload. Ramp protocols are recommended because of continuous increase in workload that shows a linear correlation with the haemodynamic and ECG response, and because of a more precise estimation of the exercise capacity. In addition, ramp protocols allow workload individualisation in patients with varying exercise capacity to achieve peak exertion within the optimal time frame during the testing. The proposed testing protocols are shown below.

Protocols with graded workload increase (workload at 8–12 min of exercise given in parentheses):
— Treadmill test [8, 20]:
 • Bruce (10.2–13.5 MET)
 • Cornell (5.8–8.7 MET)
 • Modified Naughton (5.4–6.9 MET)
 • Modified Bruce (4.6–7.1 MET)
— Cycle ergometer test [8, 20]:
 • 50 W increment every 3 min (150–200 W)
 • 25 W increment every 2 min (100–150 W)
 • 25 W increment every 3 min (75–100 W)

Protocols with continuous workload increase (ramp):
— Treadmill testing (workload at 8–12 min of exercise given in parentheses):
 • BSU/Bruce ramp protocol according to Kaminsky et al. (9.4–13.9 MET) [21]

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 • American College of Sports Medicine (ACSM) ramp protocol (7.4–10.7 MET) [22]
 • American Association of Cardiovascular and Pulmonary Rehabilitation (AACVPR) ramp protocol (6.5–10.1 MET) [23]
— Cycle ergometer testing — suggested ramp protocols for cycle ergometer testing according to the American Thoracic Society/ /American College of Chest Physicians (ATS/ACCP) (workload at 10 min of exercise) [24]:
 • Ramp 30/min (300 W)
 • Ramp 25/min (250 W)
 • Ramp 20/min (200 W)
 • Ramp 15/min (150 W)
 • Ramp 10/min (100 W)
 • Ramp 5/min (50 W)

INDICATIONS FOR TERMINATION OF EXERCISE TESTING

Absolute indications for termination of exercise testing [3]:
— ST-segment elevation (≥ 0.1 mV) in leads without pre-existing pathologic Q waves (other than aVR, aVL, and V$_1$)
— Drop in systolic blood pressure > 10 mmHg despite an increase in workload when accompanied by any other evidence of ischemia (clinical or ECG)
— Severe typical angina
— Neurological symptoms (ataxia, dizziness, presyncope)
— Signs of poor perfusion (pallor or cyanosis)
— Ventricular tachycardia (VT), occurrence of atrioventricular block (second- or third-degree), loss of cardiac resynchronisation pacing
— Technical difficulties in monitoring the ECG or blood pressure
— The patient's request to terminate the study

Relative indications for termination of exercise testing [3]:
— Rapidly progressing ST depression (horizontal or downsloping) (> 2 mm) or a sudden change in the cardiac electrical axis
— Drop in systolic blood pressure > 10 mmHg despite an increase in workload in the absence of other evidence of ischaemia
— Increasing chest pain
— Severe fatigue, wheezing, leg cramps, claudication
— Arrhythmias other than VT, i.e., multifocal single ventricular ectopy, ventricular couplets, ventricular bigeminy, supraventricular tachycardia, bradyarrhythmias
— Exaggerated hypertensive response (systolic blood pressure > 250 mmHg or diastolic blood pressure > 115 mmHg)
— Development of bundle branch block or intraventricular conduction disturbances that cannot be distinguished from VT

PARAMETERS EVALUATED DURING EXERCISE TESTING

Clinical, haemodynamic, and ECG parameters should be evaluated during exercise testing [1, 3, 4].

Clinical parameters:

— Anginal pain (severity, increase, timing)

— Degree of perceived exertion (rated using Borg scale)

— Peak exercise capacity (MET) for treadmill testing or peak tolerated workload (W) for cycle ergometer testing

— Relative exercise capacity (%)

— Duration of exercise (minutes and seconds)

— Occurrence of symptoms necessitating test termination (dizziness, fatigue, shortness of breath, leg pain)

Haemodynamic parameters:

— Systolic and diastolic blood pressure at each workload stage

— Heart rate at rest, peak workload and 1 min of recovery

— Achieved percentage of maximum heart rate (%)

— Heart rate decrease at 1 min of recovery

— Maximum heart rate for a given patient

— Chronotropic response (achieved percentage of maximum heart rate, heart rate reserve, chronotropic index)

— Double product (peak systolic blood pressure multiplied by peak heart rate)

— Dynamics of systolic and diastolic blood pressure changes

ECG parameters:

— 12-lead ECG should be recorded from the torso leads at baseline, at peak workload, and during recovery

— Assessment of ST changes in at least three consecutive cycles, taking into account averaging of computer-generated signal and raw data (to exclude artefacts) at baseline, during each workload stage, and during the recovery stage for at least 5 min or until resolution of ST changes and return of heart rate and blood pressure to baseline values

— Baseline ST depression should be taken into account

— Measurement of ST changes at 60–80 ms after the J point

— Assessment of the type of ST depression — horizontal, downsloping, upsloping

— Number of leads with ST changes, timing of their recovery, and the characteristics of changes during the recovery phase

— Assessment of arrhythmias and conduction disturbances

TEST REPORT AND CONCLUSIONS

The test report should include information about [1, 3, 4, 18]:

— Test protocol

— Reason for test termination (fatigue, pain, ECG changes, arrhythmia, heart rate limit, other)

— Perceived exertion (rated using Borg scale)

— Severity of pain

— Peak exercise capacity (MET) or peak tolerated workload (W) (for cycle ergometer testing)

— Relative exercise capacity (%)

→

— Heart rate at peak exercise and achieved percentage of maximum heart rate

— Maximum blood pressure values

— Description of exercise-induced ST changes or their absence (characteristics, severity, number of leads, timing of recovery)

— ST/heart rate index (mV/bpm) (recommended optionally, if calculation is technically feasible)

— Heart rate decrease at 1 min of recovery

— Chronotropic response taking into account drugs taken by the patient

— Description of arrhythmias and conduction disturbances if present (in particular ventricular arrhythmia during recovery)

— Duke treadmill score — calculator available at: http://www.cardiology.org/tools/medcalc/duke/

— It is recommended to report the test result as "positive" or "negative" (clinically or electrocardiographically) in the case of testing performed for the diagnosis of CAD, while in other cases, the terms "normal" or "abnormal" are preferred, with description of the identified abnormalities

— In the case of testing performed for the diagnosis of CAD, the term "nondiagnostic test" should be used if 85% of the maximum age-predicted heart rate has not been achieved

— Final conclusion based on clinical and ECG evaluation, with possible suggestions regarding further investigations

TEST RESULT ARCHIVING

The test report is handed to the patient in a paper form, authorised by the physician who supervised and interpreted the test, and it should include at least a title page with patient data and test result interpretation, a summary of exercise parameters, and pages with averaged lead tracings from each testing stage with ST changes shown. It is recommended to archive results in an electronic form in at least two copies (in case of data loss) — in the memory of the computer used for the exercise testing and a backup copy (using external memory or a data server).

DURATION OF THE TEST, FUNDING, AND REIMBURSEMENT

Electrocardiographic exercise testing is a separate procedure. It should be separately billed, taking into account the cost of labour of the nurse/technician and the physician supervising and interpreting the test. The minimum time for patient preparation and test conduct is 30 min, but it may be extended to 60 min in case of complications necessitating prolonged patient follow-up or implementation of appropriate measures (e.g., when urgent hospitalisation is needed).

SUMMARY

Electrocardiographic exercise testing remains a major diagnostic and investigative tool in contemporary cardiology practice. Although its diagnostic importance has somewhat decreased

in the current era of rapid development of anatomical and functional imaging methods, its prognostic role is increasing not only in CAD but also in other cardiovascular conditions.

Conflict of interest: *none declared*

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