ISSN: 0212-8799

Archivos de medicina del deporte

Órgano de expresión de la Sociedad Española de Medicina del Deporte

Suplemento 1
Volumen 33
2016

Stress tests in Sports Medicine

Consensus Document of the Spanish Society of Sports Medicine (SEMED-FEMEDE)

Coordinators:
Pedro Manonelles Marqueta
Luis Franco Bonafonte
José Naranjo Orellana

Archivos
de medicina del deporte

Volumen 33 - Suplemento 1 - 2016

Stress tests in Sports Medicine. Consensus Document of the Spanish Society of Sports Medicine (SEMED-FEMEDE)

Pedro Manonelles Marqueta, Luis Franco Bonafonte,
José Naranjo Orellana (coordinadores);
Daniel Brotons Cuixart, José Calabuig Nogués, Carmen Calderón Soto,
Carlos De Teresa Galván, Miguel Del Valle Soto, Vicente Elías Ruiz,
Mercedes Galindo Canales, Piero Galilea Ballarini, Fernando Gutiérrez Ortega,
Fernando Huelin Trillo, Ricardo Jiménez Mangas, Emilio Luengo Fernández,
Begoña Manuz González, Fabio Pigozzi, Juan Ribas Serna,
Francisco Javier Rubio Pérez, Luis Segura Casado,
Nicolás Terrados Cepeda, Carmen Vaz Pardal

Índex

Presentation

The stress tests (ST) in Sports Medicine (SM) constitute one of the fundamental contents of a specialty that has as main object the sportsman, healthy or with some type of pathology, and that centers a great part of its activity in the evaluation of the consequences that the exercise has on the organism.

It was necessary to address the ST methodology in the area of SM, firstly because it was an in-depth subject; secondly, because the demand and needs of this procedure both healthy and sick is increasing; and third, to clarify aspects that relate to the competencies of different professions.

This work constitutes a tool of undoubted value for professionals of the SM and related sciences, because it defines with precision the fundamentals, the methodological aspects, the utility and the scope of realization of the ST.

Introduction

ST is a procedure of great use in SM because the target population of work in SM is increasing due to the increment of practitioners of physical-sport activity. In addition, ST's are used in increasingly large and numerous areas, such as pathology diagnosis, functional assessment, scientific training support, detection of sports talents and exercise prescription, as well as research at all its extremes.

In this paper, all these aspects are thoroughly reviewed and the classification of recommendations that the American College of Cardiology (ACC) and the American Heart Association (AHA) are used in terms of scientific evidence level:

- *Class I:* evidence or general agreement that the procedure or treatment is useful and effective.
- *Class II:* the evidence is more debatable or there are divergences in opinions about the utility / effectiveness of the procedure or treatment.
  - Class IIa: the weight of evidence / opinion is in favor of utility / effectiveness.
  - Class IIb: utility / efficacy is less substantiated by evidence / opinion.
- *Class III:* there is evidence or general agreement that the procedure or treatment is not useful and effective, and in some cases can be dangerous.

The sources of evidence are categorized as:

- *Type A evidence:* based on randomized, controlled and prospective studies, with high number of patients, quality statistics.
- *Type B* evidence: based on short, not necessarily randomized studies, observational cohorts, or case reports.
- *Type C* evidence: expert opinion.

Even knowing that the exercise of the SM has its peculiar characteristics (habitual work with healthy people, with high levels of physical performance and frequently in the context of competition, even of the highest level), the realization of ST in all its aspects, as well as their indication and interpretation, should be done not only in the individual context of the subject but, more importantly, in the clinical context of the athlete / patient. This is something that is part of the doctor's responsibility. Therefore, the recommendations made in the document should be interpreted as support guides that the corresponding practitioner may apply or modify according to his / her knowledge and experience to fit each individual athlete / patient.

Basis and physiology of stress test

Definition and objectives of the exercise test in sports medicine

Definition

For more than 60 years, EP has always been a tool for medical diagnosis in the field of cardiology as well as in the field of pulmonology[1,2,] to such an extent that it is not possible to find an "official" definition of ST that does not Implies its conventional use as a procedure for the diagnostic and prognostic evaluation of patients with ischemic heart disease.

Throughout the time have been added possibilities of study to this test, so that at present its use is widely extended in the SM and, by extension, in the functional assessment of athletes of any level. In fact, in the latest versions of the AHA[3] clinical guidelines, we will find objectives of the ST such as "physical capacity assessment and effort tolerance" (understandable from a clinical point of view), and even useful for prescribing physical activity[4].

PE can therefore be defined as a non-invasive procedure that provides diagnostic information on cardiopulmonary functioning and assesses individual ability to perform dynamic exercise[5]. From here, according to the medical specialty in question, you can get the applications you want (cardiology, pulmonology, SM, occupational medicine, etc.), but it will never lose its diagnostic character, since it is an essential part of the preventive arsenal in SM for the detection of occult heart diseases and other causes that may limit or contraindicate the practice of physical exercise. Therefore, regardless of the purpose of the PE, it must be performed in a laboratory with the basic equipment and the appropriate personnel to ensure at all times the safety of the subject performing the test (whether patient or healthy subject)[5].

Goals

In SM, ST can be performed for the following purposes:

- To assess individual ability to perform dynamic exercise.
- To evaluate the responses of different systems to exercise (cardio-circulatory, respiratory, metabolic, etc.).
- To obtain useful data for performance improvement.
- To obtain data to prescribe exercise in an individualized way.
- To assess the general health of the subject and, if necessary, detect

unknown anomalies that could limit or contraindicate the practice of exercise.

- To evaluate the behavior of certain pathologies in relation to the effort (patients with heart disease, hypertension [HT], muscular pathologies, respiratory diseases, etc.).
- Diagnosis, prognosis and assessment of pathologies directly related to stress (ie, exercise-induced asthma).

In addition to these aims, the EP must always be done in[1]:

- Asymptomatic athletes, over 35 years old and with two or more risk factors as an assessment of fitness for sports practice.
- Asymptomatic athletes under 35 years of age with a family history of unexplained sudden death related to exercise in first-degree relatives.

For all these reasons, the EP cannot be performed by unqualified personnel with the excuse of isolating some of its functions (for example, the exclusive assessment of sports performance), since all are linked, and are frequent in cases where an athlete, apparently healthy, reveals some pathology in a ST that was unknown and that becomes evident during the exercise. For this reason, one of the fundamental elements of the EP (accepted by all international scientific societies) is the correct monitoring during the test of a 12-lead electrocardiogram (ECG)[1-3,6,7], as well as the existence of the appropriate emergency equipment and qualified personnel to use it[8,9] in the room, regardless of the purpose of the test.

On the other hand, in the assessment of sportsmen and women, ST should preferably be performed with the simultaneous analysis of ECG, ventilation and gas[3,4] analysis, unless the objective of the same is strictly the cardiac assessment with a diagnostic purpose.

Exercise physiology in the stress test. Physical exercise types

Physical exercise is an activity performed by all human beings, to a greater or lesser extent, from when they are born until they die, and which involves the mechanical and metabolic activation of the different organs and systems of the organism as a result of muscular activity. It is also planned, structured, repetitive and intentional physical activity with the objective of improving or maintaining one or more of the components of the physical condition[10].

During the year there are adaptive changes that affect the different organs and systems, which will produce functional responses depending on the intensity and duration of the physical activity developed.

Physical exercise causes functional changes in the body, which can be considered as responds to stress with an adaptive syndrome, which manifests acutely during the exercise and is called "response to effort," and which is manifested by the structural and functional changes of the acute adaptations and is called "exercise adaptation".

These responses and adaptations vary depending on the intensity, duration and frequency of physical activity developed, as well as other environmental factors or circumstances.

Exercise types

There are three types of exercise in relation to the mechanical properties of muscular action[12]:

- *Dynamic / isotonic:* when it causes the displacement of a part of the body. Within this type there are two different exercises.
  - 1. Concentric: when there is shortening of muscle fibers.
  - 2. Eccentric: when there is an elongation of these fibers, such as when acting against gravity.
- *Isometric:* when there is no modification of the length of the fibers even though there is muscle tension. It happens when you apply a force to something that cannot move.

There are other ways to classify physical exercise, for example according to the volume of muscle mass involved: local, regional and global exercises; or according to the type of work performed: strength, speed, power and endurance (and their combinations, such as strength-endurance or force-velocity).

Metabolic classification refers to the availability or not of oxygen for muscle contraction, which is a function of exercise duration, differentiating between aerobic (in the presence of oxygen) and anaerobic (in the absence of oxygen) exercise[13].

Usually the exercises are complex and involve both dynamic and static contractions, as the metabolism combines anaerobic phases with other aerobics, so the physiological responses are very variable.

At the moment, in the EP mainly exercises of predominance dynamic and aerobic are evaluated.

The duration and intensity of the exercise determine the energy supply system, which is another way of differentiating the different types of physical exercise, and which is fundamental to understand the metabolic dynamics of a moving body.

The intensity with which an exercise is performed marks the individual capacity to do a work and indirectly defines the quality of the oxygen transport system from the time it is inhaled in the atmospheric air until it is used in the muscular action, being able to determine the maximum efficiency respiratory rate corresponding to a determined effort intensity (aerobic threshold). If the intensity increases and is not assimilated in the organism, fatigue appears, considering this situation the anaerobic threshold[14].

Short duration and high intensity tests require rapid and immediate energy input. This energy is provided by adenosine triphosphate (ATP) and creatine phosphate (CrP), which accumulate in the muscles. This amount of energy is very scarce, so it limits the intense and immediate muscle activity to a few seconds, after which other energy sources have to come into play. The amount of energy generated by the ATP-CrP system (phosphagen system) is necessary for very short duration actions, such as weight throw, high jump or long jump, or gymnastic acrobatics, for example.

In other activities of longer duration, such as football or hockey, these specific explosive actions occur during the match. In order to supply this extra energy, it is necessary that the ATP-CrP system is regenerated with other supply systems, so that the phosphagens are continuously resynthesized, resulting in an overlap of the different energy systems. This system is used in exercises of less than 15-30 seconds duration and high intensity.

If exercise lasts longer, muscle glycogen provides the energy needed to phosphorylate adenosine diphosphate (ADP) through anaerobic glycogenolysis, forming lactate. In the absence of oxygen, pyruvate is converted to lactate, which maintains the rapid formation of ATP, essential in activities that need an extra contribution when the phosphagen deposits are overcome. This situation can occur in the final sprint of a test of 1,500 meters, or in very fast plays in an ice hockey match or football, for example.

If this situation continues over time, the lactate accumulates, but as there are situations of rest or recovery, it facilitates its elimination allowing the activity to continue[15].

The preference for using these metabolic pathways is because they are very fast in providing energy in the form of ATP.

If physical activity persists, the energy comes from aerobic metabolism, in the presence of oxygen, which requires a greater supply of blood. It is a much slower way to obtain energy, whose substrates, as major fuels, are free fatty acids.

In very long-term exercises, amino acids can also be used as an energetic substrate, especially branched chain aminoacids, which are excreted by the liver and used in muscle.

These systems of energy production are based on their contribution maintained by the simultaneous resynthesis of ATP, which is obtained from oxygen-free breakage of glucose and glycogen to pyruvate or lactate, and the oxidation of fats, carbohydrates and even proteins.

The aerobic route is the most profitable for the body (greater production of ATP) and with end products that do not produce fatigue, being the most important metabolic pathway in long-term exercises.

For physical activity, the muscle is nourished by different substrates provided by the diet and by the reserves accumulated by the body.

As we have seen, energy sources are three, which overlap and are used in function of the activity being developed, and the intensity and duration of this activity are decisive for a source or another predominantly.

Cardiovascular response to exercise in normal subjects

Among the many types of exercise (static, dynamic, concentric, eccentric, aerobic, anaerobic, etc.) that could be used to evaluate cardiovascular response to exercise, exercise is usually an activity that has dynamic properties and an aerobic component or resistance. In fact, two of the exercises most frequently used during ergometry are walking / running on a treadmill, with possibility of slope change, and pedaling on a bicycle with power calibration. Both exercises put into action sufficient muscle mass to force a physiological response of the cardiovascular system.

Muscular activity requires a supply of energy according to the level of activity. This energy can be obtained from the circulation and work of mitochondria (aerobic metabolic pathways) or from internal energy sources (CrP, glycogen, glucose) through "anaerobic" metabolism (anaerobic glycolysis) with insufficient energetic supply of the mitochondria . During a progressive exercise from rest, while the muscles in activity pull the aerobic metabolic pathways, the cardiovascular system is responding depending on the intensity of muscular activity. This is usually the norm for work intensities from rest to 70% of the maximum for a subject. With higher percentages of intensity, anaerobic metabolic pathways enter into action.

When the demand for energy or work during exercise time cannot be satisfied with the energy supplied by the mitochondria and their corresponding oxygen supply by the cardiovascular system, the "anaerobic" metabolic pathways are used. Since the activation of the anaerobic pathways generates plasma markers such as lactatemia, in addition to changes in ventilation patterns, the temporal course of the use of the anaerobic metabolic pathways during an ergometry can be followed.

The response of the cardiovascular system during an ergometry has basically been measured with three variables: cardiac output (heart rate), heart rate (HR) and blood pressure (BP). Measurement of cardiac output requires indirect techniques, such as the Fick principle, either by dilution of vital dyes, by thermodilution or by oxygen consumption (the latter less invasive), by ultrasound or by radioisotopes. Direct or invasive measurement of cardiac output is only practiced under experimental or highly specialized conditions. The HR can be measured with the ECG or with pulse meters while BP is determined with a sphygmomanometer and auscultation. Since the ratio of oxygen consumption to work on an endless belt is very well established, in addition to being the subject of another chapter, it is not to be used here as a reference or, in any case, as its metabolic equivalent or MET (1 MET = 3.5 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$).

The cardiovascular response to exercise varies depending on the intensity of exercise. Muscles extract blood components for their metabolism, and the most significant representative of these components is oxygen (necessary for mitochondrial oxidation and ATP production to be blocked). The extraction of oxygen by the muscles can be measured by the arteriovenous difference. This arteriovenous difference is quantified by measuring the partial oxygen pressure in an arterial blood sample and a venous blood sample, and finding the difference. The value of the arteriovenous difference usually reaches a maximum r of 15-17 ml of oxygen per 100 ml of blood during maximum intensities of exercise.

When the intensity of the exercise is increased, the local physiological processes, that is, of the muscles that are working, generate stimuli that, once detected by the central control systems (nervous system, endocrine system, etc.), induce to a generalresponse tending to maintain homeostasis in the new circumstances. This response takes between 2 and 3 minutes to stabilize. For this reason, periods of work intensity increments are usually maintained between 2.5 and 3 minutes in any of the ergometers used during stepped tests.

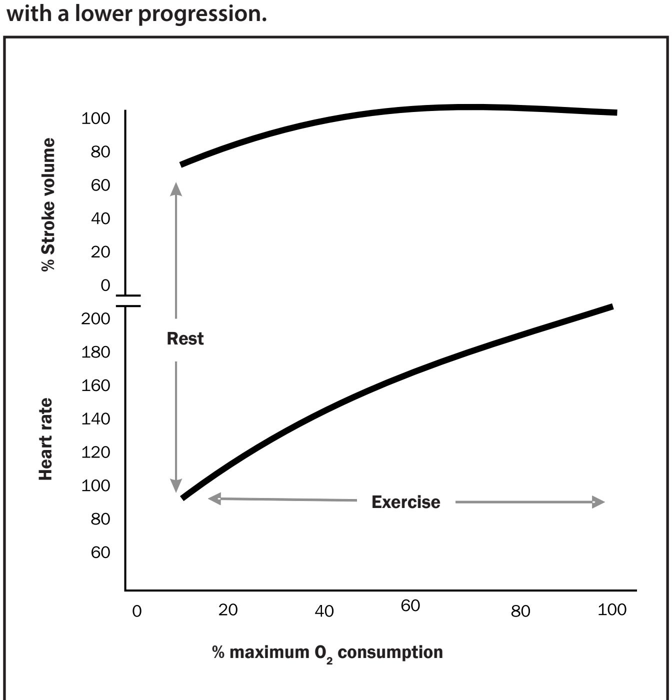
One of the early consequences of increased muscle work is the decrease in peripheral resistance to blood flow in the active muscle territory (the production of heat, carbon dioxide, hydrogen, adenosine, etc., converge to produce vasodilation). This increases blood flow to the active muscles. In these circumstances, the cardiovascular system must be able to meet the demand for flow through the active muscles, in addition to the flow to essential organic territories (brain, own heart, lungs, skin cooling system, etc.).

Initially, the cardiovascular response consists of an increase in cardiac output and BP. Cardiac output increases at the expense of an increase in left ventricular ejection volume and an increase in HR. BP is increased by an increase in systolic BP (SBP) and a decrease or stabilization of diastolic BP (DBP), so that the mean pressure slightly increase while the differential pressure does it strongly.

As exercise intensity increases, ejection volume tends to stabilize and most of the increase in cardiac output is done at the expense of HR increase (Figure 1). In high-level athletes, the stabilization of the ejection volume usually occurs at intensities closer to the maximum and can reach six times the values of the rest.

The chronotropic response during exercise is determined by the decrease in the activity of the parasympathetic nervous system and the increase of the sympathetic nervous system. During an exercise of increasing intensity, the HR first ascends at the rate of about 10 bpm for each MET of increasing work, and then increasing more slowly depicting a kind of gentle slope or plateau with the maximum working intensities. The maximum HR (HRmax) has been estimated by numerous equations that relate it to age, weight, sex, etc. Of these, the most used for its simplicity (not for its accuracy) is FC = 220 - age in years. Even so, the variability between subjects can reach more than 12 bpm in equal conditions.

Figure 1. Representation of the heart rate (HR) evolution and the volume of systolic ejection (in percentage) during a progressive exercise to the maximum. It is observed that both HR and left ventricular systolic ejection volume increases up to intensities of 50-60% of maximum oxygen consumption; afterwards, systolic ejection volume stabilizes and HR continues to increase, although with a lower progression.



For a correct interpretation of the chronotropic response during an ergometry, a series of factors and conditions that affect the HR values must be taken into account. In relation to the previous paragraph, the older the age the less the value of HRmax and submaximal HR. Regarding the type of exercise used, the dynamic exercises produce a greater increase of the HR than the isometric exercises or the calls of force. Likewise, the training state can cause the slope of increase of the HR to vary during the work steps. For example, after prolonged bed rest, HR can be greatly accelerated with low or submaximal work intensities. On the contrary, in a subject trained for resistance exercises, the HR in submaximal stages may be lower than that of an untrained subject, despite the fact that in the end the HRmax is reached.

Other conditions may affect the evolution of HR during ergometry. For example, anemia, altered volume of body fluids (dehydration, plethora), metabolic involvement (hyperthyroidism, aldosteronism, etc.), a decrease in peripheral resistance or ventricular dysfunction, or an increase in environmental temperature can raise the chronotropic response for the same level of work. Conversely, a high level of training (especially endurance training), atrial sinus disease (chronotropic incompetence), heart disease, or treatment with beta-blockers may result in a decrease in HR at similar levels of submaximal work.

The recovery of baseline HR values after ergometry offers interesting aspects to evaluate. The chronotropic response after exercise showed a rapid fall in the first 30 seconds after exercise, followed by a much slower fall and minutes of duration. During the recovery phase, the activity of the parasympathetic nervous system is restored, which makes evident its bradycardic effect and the increase of cardiac variability. Any abnormalities (arrhythmias, tachycardias, etc.) during the recovery process may have a high prognostic value. However, the occurrence of isolated extra-systoles during recovery after exercise, by itself, has no diagnostic value[17].

BP depends mainly on blood volume, cardiac output, peripheral resistance and stiffness of the vascular wall. During exercise, SBP rises at the rate of about 10 mmHg per MET, with higher rates for the female sex and for the more advanced ages. The average pressure does not rise so much because of the fall in the DBP. The recovery of the resting SBP values after reaching the maximum exercise intensity takes about 6 minutes, and remains below the rest values for several hours. Abrupt termination of the exercise at the end of an exercise test (especially when the subject performs exercise in the orthostatic position) can lead to a sudden fall in SBP and a transient loss of consciousness as a result of accumulation of blood in the venous territory High capacitance), as well as a rapid increase in peripheral resistance[18]. This hemodynamic behavior advocates a gradual stopping of the exercise performance after an ergometric test, especially if it has reached the maximum intensity.

Another point of interest in the recording of BP values during ergometry derives from its relation with the consumption of myocardial oxygen. A positive correlation has been found between HR, BP, diastolic volume and oxygen consumption by the myocardium, with the best correlation being the voltage-time index[19], which is equivalent to the HR product by the SBP and by the systolic contraction time. Myocardial oxygen consumption depends on heart rate, contractility and wall stress (the latter is the product of left ventricular volume pressure divided by the thickness of the ventricular wall). Its measurement would require a coronary catheterization and measurement there of the oxygen content. Instead, a simplification of the voltage-time index is used which consists of the product of the SBP by the HR (also called double product), that in normal conditions oscillates, respectively, between 8,000 and 40,000 for the rest and the maximum intensity of exercise of a normal subject. Under normal conditions, the myocardium receives 5% of the cardiac output regardless of the intensity of work. However, when there are alterations in the coronary flow, generally an ischemia, this is reflected in the values of double product.

Oxygen consumption (VO_2) is the amount of oxygen the body uses from atmospheric air, and maximum oxygen consumption (VO_2max) is the maximum amount of oxygen the body can absorb, transport and consume during maximum physical exercise[20]. It is considered the best variable related to the cardiovascular state and the capacity to exercise. In addition, the relationships between work intensities and oxygen consumption per kilogram are known with reasonable precision[21].

A primary aspect of ST in SM is the evaluation of the generally aerobic performance that, conditioned by genetic aspects, age and sex, is modified by training, especially endurance training. Hence, in this type of PE, VO_2max is the most evaluated parameter[22].

Another useful variable in the evaluation of cardiovascular performance is the so-called anaerobic threshold (AT), defined in 1967 by Wasserman as the intensity of exercise or work from which progressively increase ventilation and blood lactate concentration, regarding to VO_2[23]. This variable is highly reproducible and can be used to define submaximal or "sub-threshold" intensities. In case of not using fast registers of respiratory gases during an ergometry, the AT can be estimated from a recorder of the thoracic movements or micro-samples of blood for determination of the concentration of lactate in plasma.

Requirements for a stress test

Basic preconditions

Prior to the execution of the ST, in compliance with the Organic Law 15/1999 on the protection of personal data[24], the patient is informed that personal data, including those of health, are necessary to carry out the tests that are incorporated into a file, where they will be treated in a confidential way and in accordance with the security measures contemplated by said Law and its Regulation of development 1720/2007. You will also be informed that your record will be kept during the mandatory deadlines established in the Health Ordinance of each County or Autonomous City.

The patient should be informed about the importance of the test, its usefulness, the methodology followed and the risks involved[25].

Once the patient has understood the test to be performed, he must sign the corresponding informed consent.

In those patients who are taking medication, it will be necessary to evaluate the possibility of suspending it prior to the test, since the results might be influenced[25].

The patient will not be able to eat or drink caffeine in the 3 hours prior to the test (caffeine is present in coffee, tea, certain soft drinks, chocolate and certain painkillers that do not require a prescription), but ST cannot be performed after an extended fast. If you are a smoker, it is recommended not to smoke for 3 hours before the test.

It is recommended to avoid intense physical activity or unusual exercise in the previous 12 hours.

ST will be made with sports clothing and footwear.

Prior to the test, a brief personal and family history will be carried out, as well as a physical examination in order to determine some type of contraindication or detect any clinical signs that may indicate the lack of convenience of the ST[4].

A 12-lead resting ECG should be performed in the supine position before exercise and compared with the pre-exercise ECG (sitting on the cycle ergometer or standing on the treadmill), since, as the electrodes of the limbs are in the trunk, there may be changes in voltages or waves. A tracing will also be performed after a phase of hyperventilation in case of possible diagnosis of ischemic heart disease[3,26,27].

Careful preparation of the skin is necessary in order to obtain quality electrocardiographic records. To do this, the area should be shaved and an alcohol swab should be used to clean the skin areas where the electrodes are to be placed[1,27].

It is advisable to place a mesh in the form of a T-shirt to hold cables and electrodes so that their stability is maintained throughout the ergometric test[1].

Staff of realization

The personnel who perform the ST are fundamental because it guarantees the correct planning and the proper execution of the test, the interpretation of the symptomatology and of the physical signs, the correct treatment of any clinical situation that may appear, the proper interpretation of the studied parameters and the proper report. Therefore, any ST must be supervised and directed by an experienced doctor who will be responsible for the quality of the ergometry room and patient safety.

The doctor, who must have experience in ST, is responsible for the interpretation of all the test data (signs, symptoms, ECG, parameters studied), must be trained in emergency situations and cardiopulmonary resuscitation (CPR), Ideally accredited and periodically re-accredited following the guidelines of the National CPR Plan (which has been in place in Spain since 1985) and the European Resuscitation Council, and should address the complications of the test, if necessary.

The technical or nursing staff prepares the healthy individual or the patient placing the electrodes and the cables, and other technical aspects, and during the test measures the AP and collaborates in the evaluation of the patient's symptoms and signs and in the execution of the test[1].

The personnel directing the test must be adequately trained and updated in all emergency procedures, EP contraindications and indications for the end of the test, which must be strictly followed[28]. In addition, the presence of a doctor is required for the assessment of the electrocardiographic and clinical findings, because there is a great deal of variation in terms of abnormal outcome criteria[29].

The ergometry is a diagnostic test and, as such, must be performed by a doctor following the Law 44/2003 of November 21[30].

The scientific consensus in this aspect is unanimous and has prestige bibliographical supports[3,6,31], which expose the competences and the knowledge required by the doctor who performs ST's. Among them, it emphasizes the knowledge of the indications and contraindications of the tests, the basic physiology of the exercise, the principles of interpretation and the emergency procedures.

The doctor must be assisted by a second person (nurse or doctor), also trained in ST and in emergency situations.

Exercise room

The ergometry room[1] should be spacious and located in an area that is easily accessible and capable of rapid evacuation in emergency situations, allowing the passage of stretchers and other means of emergency evacuation, in the event of a cardiological event o r of another nature that requires the transfer to a hospital. It has to be a bright room, well ventilated, dry and spacious, so that professionals can circulate well between the different devices that support the test.

The room must have constant environmental conditions that favor the dispersion of the sweating and the heat that causes the exercise, with a temperature between 18 and 22 ºC and a relative humidity of 40-60%. In this way, the heat, humidity and their consequences will not affect the development and the test, the answers or the analyzed parameters.

It is preferable to use a ground floor to locate the ergometry room, so that the structure of the building supports the weight of the ergometer well and there is no risk of vibration and collapse. The steps will be avoided inside the room, and if there are several levels in it, ramps will be used so that the devices, patients and medical personnel can move easily. The height of the room should be high enough to be able to perform an ergospirometry for athletes of high stature, taking into account a possible increase in the slope of the treadmill.

In addition, you must have a communication system to quickly report emergency situations.

Material resources

For the realization of ST, ergometers are necessary; Monitoring systems for cardiovascular parameters that are modified with effort and that need to be recorded and assessed during ergometry, such as HR, BP and ECG; ergometer or expired gas analyzer; pulse oximeter and other materials.

Ergometers

For the realization of PE, it is necessary to use ergometers, which are described in a later section.

Electrocardiograph

An adequate electrocardiographic recording system is essential for continuous cardiac rhythm monitoring and assessment of electrocardiographic changes during exercise and recovery. In the market there are computerized equipment, from very sophisticated and expensive to other simpler and conventional, but all must[32]:

- Have a record with a good view of the electrocardiographic image.
- Accurately identify changes in the ST segment.
- Continuous monitoring of a minimum of three leads with oscilloscope, to identify patterns of arrhythmias.
- Have the ability to print the 12 leads of the ECG for later review and improve interpretation.

To correctly diagnose some arrhythmias and to observe changes in the ST segment that are sometimes only visualized in some leads such as the lower ones, it is necessary to have the 12 leads of the ECG. There are equipment with an automatic arrhythmia detection system that, while not essential, may be practical in high-risk populations.

To minimize movements it is advisable to use silver or silver chloride disposable adhesive electrodes, which are the most reliable and available in different size and adhesive models. The use of an elastic tubular mesh to fix the electrodes and cables, and to attach the armored cable bag to the waist of the patient, stabilizes the electrocardiographic signal.

Blood pressure control

The monitoring of BP during exercise by the manual system with stethoscope and sphygmomanometer remains the most reliable and easy to use method. Care should be taken to place the cuff at the level of the heart and to use the appropriate size for the subject to be assessed[33], so that different sized cuffs should be available. Digital and aneroid sphygmomanometers have replaced, without improving reliability, mercury manometers; They requires periodic calibration and proper maintenance. Automated AP measurement equipment is expensive and of dubious reliability at high exercise intensities due to the distortion caused by movement.

Ergometer or expired gas analyzer

Assessing ventilation (VE) per minute and parameters of respiratory gas exchange, oxygen consumption (VO_2) and carbon dioxide production (VCO_2), in combination with traditional ST procedures, is known as ergospirometry or stress test Cardiopulmonary.

The cardiopulmonary exercise test provides the doctor with a very accurate, reliable and complete evaluation of the behavior of cardiovascular and respiratory devices and of energy metabolism during physical exercise, which is very useful and applicable in different medical specialties (Cardiology, pulmonology, SM and occupational medicine). It is a fundamental tool in the assessment of the athlete from two areas: the protection of the health status of athletes through prevention and early diagnosis, and scientific support of training.

Current devices contain rapid O_2 and CO_2 analyzers, which obtain data even from each breath, which facilitates non-invasive quantification of VO_2 during dynamic exercise. VO_2max is the maximum amount of oxygen that the body is able to extract, transport and use in tissues, and is considered the best index of cardiorespiratory fitness and functional exercise capacity[33]. The determination of VO_2 allows to objectively estimate the functional deterioration and to evaluate the therapeutic measures. Ergospirometry is a bloodless and reproducible procedure that can be repeated as many times as necessary and allows better evolutionary control of the patient.

The effort exerted by the subject (respiratory quotient: VCO_2 / VO_2) and other variables that provide valuable diagnostic and prognostic information in healthy individuals or with some pathology, such as aerobic and anaerobic thresholds, can also be evaluated in the cardiopulmonary exercise test. Those are: ventilatory equivalents (VE / VCO_2), dead space / tidal ratio (Vd / Vt), oxygen pulse (VO_2 / HR) and exhaled CO_2 partial pressure.

In patients with cardiac issues it is useful to determine submaximal parameters, such as AT in order to assess their functional capacity. It is advisable to use the HR in the AT as recommended HR to train for greater functional improvement and safety of a program[1].

Gas analyzers and flow meters tend to maladjustment, which can lead to significant measurement errors, which is why the metabolic system must be calibrated just before each ST. This includes the calibration of the air flow meter (pneumotachograph, mass flow sensor, turbine transducer ...) and O_2 and CO_2 analyzers, checking their response time and complying with the manufacturer's specifications.

Due to the fact that ambient conditions affect the concentration of O_2 in the inspired ambient air, it is necessary to take into account temperature, barometric pressure and humidity. Current equipment includes a barometric station to measure these parameters, allowing a correct calibration.

Although most systems available incorporate microprocessor controlled automatic calibration procedures, it is important to periodically validate the apparatus with appropriate quality and maintenance controls.

The measurement equipment software facilitates the processing and analysis of the multiple data obtained (respiration to respiration values, mean number of breaths, or time intervals of 10 to 30 seconds). Each software determines the type and amount of data displayed on the screen, but almost all allow the user to customize the data and graphics during the test, or in the final report. At a minimum, the V-slope graphs and the ratio of equivalents VE / VO_2 and VE / VCO_2 over time must be printed to verify the thresholds. They also have automatic detection of ventilatory thresholds by several methods, which can lead to confusion about the variables used or how they are interpreted. These values should always be reviewed and validated by a professional experienced in cardiopulmonary ST.

Pulse Oximeter

Pulse oximetry is a method of noninvasive monitoring of oxygen saturation. The measurements are based on the differential absorption of wavelength variations of the light to non-invasively estimate the proportion of oxygenated capillary hemoglobin. The vast majority of probes certify the accuracy and bias (2-3%) compared to analysis of arterial blood samples. Movement artifacts and poor capillary perfusion are sources of error in measurements during exercise, and tend to cause small underestimates of true oxygen saturation, particularly with the use of a fingertip probe. Inaccurate HR readings identify unreliable pulse oximeter data. Pulse oximeters provide an estimate of oxygenation and are used to identify trends during exercise such as safety monitoring. A decrease in oxygen saturation of more than 5% during ergometry, in in clinical protocols, suggests exercise-induced hypoxemia and requires confirmation with arterial oximetry.

Resistance athletes with high cardiovascular capacity may use their lung capacity better than less fit individuals. They may reach ventilation limits at maximal effort that produce an arterial desaturation of 5% to 10% from baseline as a result of diffusion limitation due to the rapid pulmonary vascular transit associated with high cardiac output[34]. These are indicators of limits of ability of certain aspects of the pulmonary system, which do not always indicate pathology.

Other materials

In the ST in SM it is common to determine AT by the evolution of blood lactate, also known as metabolic method. There are various models of measurement of capillary lactatemia. The simplest and most affordable are electroenzymatic or dry chemical analyzers.

Ergometers

An ergometer is a mechanical or electrical equipment that allows setting a determined workload that might be applied to the athlete.

This instrument must allow the workload to be adjusted by a quantifiable resistance. Through different physical parameters, such as speed, slope or mass, the load intensity can be modified.

The most commonly used ergometers are the step, the cycle ergometer, the treadmill and the arm ergometer.

Step test

It is an ergometer used especially in screening or filtering of large groups (sedentary or child populations) and athletes who do not have easy access to laboratories of more complex technology[35]. It consists of one or more steps that the individual must climb at a certain speed and in different ways according to the test used. The power is calculated by equations starting from standard conditions in terms of bank height and climb frequencies.

The types of tests available for this ergometer are poorly suited for specific functional assessment in most sports disciplines. Some of the disadvantages that they present are:

- It produces local fatigue in the muscle groups used to make the whole body perform the action of climbing the step.
- They do not allow the involvement of the cardiorespiratory system with the muscular and peripheral circulatory systems in similar conditions to those of competition.
- The athlete usually performs the test irregularly or incompletely if the center of gravity does not raise the centimeters of the step, resulting in an incorrect assessment.
- Despite the use of optical and acoustic timers, not all individuals are able to maintain the required rate of ascent and descent.

Cycloergometer

This is an exercise bike in which the resistance to pedaling is measured to pedaling. It can be:

- *Mechanical brake:* fixed resistance to pedaling, with constant rhythm close to 50-60 pedals per minute. In this type of cycloergometer, the resistance is placed externally in the form of a weight which tightens the belt around the wheel, so that the friction produced is proportional to the weight placed. Another variable used to control the intensity of the effort is the angular speed (rpm).
- *Electronic brake:* power is independent of speed angle, so that the variable used to set the intensity of the effort is directly the power in watts (W).

The working load can be regulated in W or in kilogram-force (Kpm) per minute (6 Kpm/min = 1 W)[1].

This ergometer has, evidently, a particular use in bicycle sports, so it must be adjusted so that the athlete can simulate the sport's gesture as best as possible.

Adjustments for a correct evaluation:

- The handlebar must have an adjustable height and competition design.
- The sit must be a competition one and be adjustable both vertically and horizontally, so that the distance between the handlebars and the sit, as well as between the handlebars and the pedals, can be varied.
- The pedals are usually used with feet stops.
- The advantages of the cycloergometer over the treadmill, which is the other most used ergometer, are its lower price, which occupies less space and that it is less noisy[3].

In addition, the ECG record is more stable. However, in people not used to this exercise it causes localized fatigue in the lower body which limits the tolerance to the SS.

Treadmill

It is the most used ergometer because it allows to develop natural movements, like the march and the race.

It consists of an endless belt driven by an electric motor and which the patient must walk or run at different speeds and slopes, according to the protocol used[1].

Although the variables that con be modified are speed and slope, in the assessment of athletes the slope is usually kept fixed at 1%. This inclination compensates the lower metabolic cost that there is in a closed place and without real displacement, where there is no resistance to air.

It is important that the carpet has a front bar and handrails on both sides, but the support in them might distort the calculated functional capacity, as it facilitates the patient's work and increases the time of effort.

It is a more expensive ergometer, which requires more space and is noisier than the cycloergometer.

Arm Ergometer

It is a machine in which some pedals are gripped with the hands and an alternative circular movement similar to the one of pedaling in a bicycle is realized.

In principle this ergometer was conceived to be able to value people with functional incapacity in the inferior train, since they can access the ergometer with its own wheelchair.

It is also used for performing anaerobic tests, such as the Wingate, of interest in sports where work is done with the arms.

The workload is regulated in W.

Kayak-ergometer

It is a machine that simulates the movement of the paddle of the canoeist. The resistance is produced through an air displacement turbine that simulates the dynamics of the water, so that this brake system allows the use of the ergometer regardless of age or level of form.

The seat of the kayak is adjustable to adjust the distance to the footrest, and the pole is usually light.

The load is regulated by the pulling force, although it has an additional mechanism for adjusting the resistance factor of the front fan.

In ST with kayak-ergometer the pace of paddling is usually adjusted with a stroke meter.

It is common for the power meter to display information about distance traveled, time, W and force applied with each arm.

As for the results obtained in the laboratory tests, there are discrepancies among the authors about whether or not the laboratory data are adjusted to those obtained in water[36,37].

Remo-meter

This ergometer offers a simulation of paddling in the water. Depending on the type of sport, we find rowers with fixed or mobile feet:

- Dynamic support: the foot carriage is free to move forward or backward on the monorail. The drive rope connects the footrest carriage with the handle and transmits leg strength combined with the upper trunk force to the fan.
- Static support: it is the seat that moves by the monorail and the footrests are fixed.

Both W and distance can be controlled on both ergometers. When used in young and inexperienced athletes, performance results in the ergometer will depend on certain anthropometric values[38].

Canadian Canoe Ergometer

This type of ergometer is based on a device in which the athlete adopts the same kneeling position as in the boat. The athlete's knee rests on an anatomical support.

The mechanical reproduction of the movement is possible using a braking system by means of a belt that is wound on a steering wheel that offers resistance when the blade moves towards the rear of the ergometer, but allows a free slip in the recovery phase. The instrument consists of two guides of 2.5 m, one on each side, so that the athlete can row on either side of the boat, through which a shovel runs through an articulated system.

The blade is connected to a cable that rotates on two pulleys, of which the first forms an integral assembly with the flywheel. To analyze the force applied in each active phase a tensiometer is applied in each blade.

This ergometer allows evaluating two athletes at the same time, one in each guide.

Ergometer for Nordic skiing

This apparatus is placed on a treadmill and, for the purpose of calculating the work done by the upper extremities, the same measuring system is used as in the Canadian canoe. The only difference is the force sensor, which consists of a linear transducer balanced by a calibrated spring located near the handle of the cane.

For the lower extremities, the device has two roller skates in the front, two rails of 2.5 m that avoid lateral deviations during the tests and, on the foot supports, two linear transducers to measure the forces acting on feet.

The test is performed with the athlete skiing on the treadmill on several slopes and at different speeds.

Swimming ergometer

This ergometer allows swimmers to simulate swimming strokes by pulling strings that propel a fan with variable air resistance.

They have an anatomical bench that slides by an aluminum monorail when pulling the blades.

Although resistance can be varied by acting on the fan or by changing the rubber, the air resistance is usually adjusted by changing the opening of the regulating door on the front of the ergometer. The lower setting, "1" (fully closed door), provides the lowest resistance, and the highest setting, "7" (fully open door), provides the highest resistance.

There are ergometer for swimmers that can be used in the water, such as the tethered ergometer or static swimming ergometer and the swimming channel or endless stream of water (flume).

Protocols

The stress protocols are the different standardized models of combination of load variables (speed, slope, realized work or developed power, strokes per minute, etc.) and time of application of these loads in the different ergometers in the ST laboratory[39].

The choice of protocol will depend on the factors described in Table 1.

The protocol is decided depending on the reason for the test and the information that needs to be obtained from it.

There are two fundamental objectives of ST, and the choice of protocol depends on them: functional assessment and health control.

Regardless of the protocol chosen, and once the subject is prepared, the ST consists of three phases: preheating, exertion phase and post-stress recovery period.

Although there are multiple protocols, they can all be classified depending on their characteristics[1], which are (Figure 2):

- Intensity:
  a. Submaximal protocols: do not take the subject to their maximum capacity of effort.
  b. Maximum protocols: take the subject to their maximum capacity of effort or exhaustion.
- Application of workload:
  a. Constant or rectangular load protocols: the load remains constant or stable throughout the test.
  b. Incremental or triangular load protocols: the load increases with time. Depending on whether or not they have pauses for sampling, these can be:

1. Continuous:

   Increase of the load without solution of continuity in the time (protocols "in ramp").

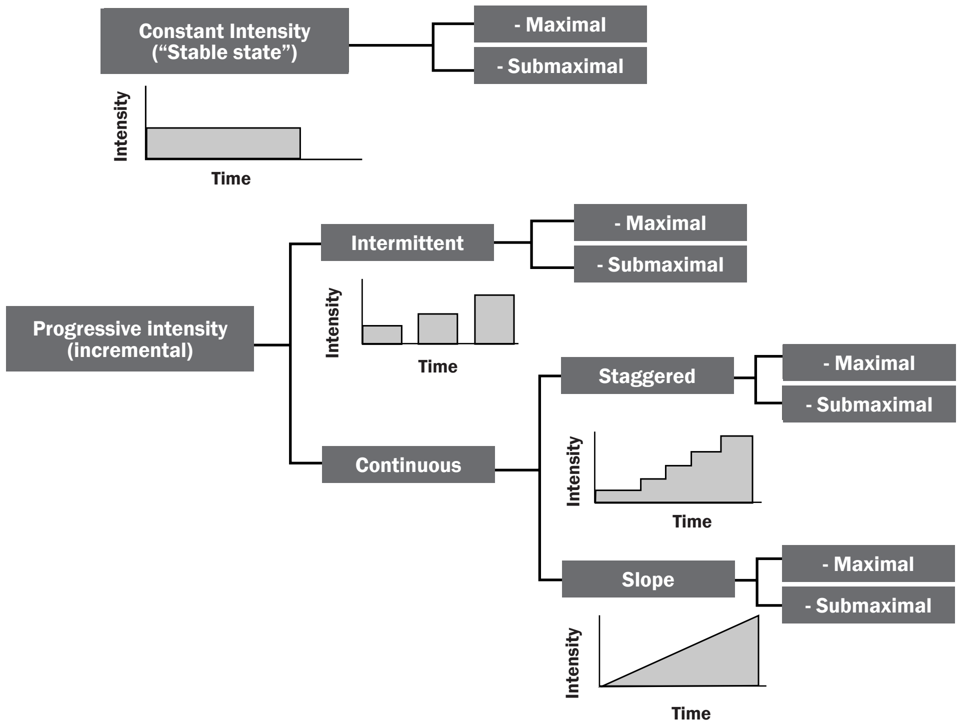
   The load is maintained for a period of time before switching to the next load ("step" protocol).
2. Discontinuous.

Submaximal ergometries monitor workloads, HR, or ECG, and other variables such as BP or subjective perception of effort. There may be no pathological change in ECG or BP. These tests can be very useful in determining the ability to maintain an effort for a long time or to

Table 1. Factors on which the choice of the protocol of the stress test depends.

- Test indication.
- Physical activity or sport performed by the person.
- Technical means available in the effort laboratory.
- Experience of the team performing the test.

Figure 2. Type of protocols.



evaluate the evolution of the physical condition in apparently healthy subjects in whom a diagnostic evaluation is not necessary. The selection of the initial load, time and progression loads should take into account factors such as weight, sex, age, fitness level of the subject evaluated and the purpose of the study. Submaximal tests are terminated upon reaching a predetermined intensity or target HR (ie, 85% of theoretical maximum HR [MTHR]).

With submaximal and indirect ergometry (without gas analyzer), the VO2max can be estimated by extrapolation to the MTHR (220 - age) of the HRs recorded in submaximal stages, based on the linear relationship between the working power and the VO_2 by tables or formulas validated for various protocols (YMCA, Astrand, PWC, ACSM ...) and ergometers40. The estimation error reaches 10-20%, despite the fact that it is minimized when using protocols with stages of sufficient duration to reach metabolically stable states.

The maximum tests involve reaching the maximum capacity of effort or exhaustion by fatigue that prevents from continuing the test. The maximum physical work capacity (maximum performance) of the individual or the last load performed is assessed. They provide more information and precision than the submaximal performances, but they have a greater risk of adverse effects.

Increased ergometry and exhaustion with electrocardiographic control is considered the best substitute[41] for the direct measurement of VO_2 by means of an ergospirometer. It is possible to estimate VO_2max by equations, which include body weight and maximum power reached (MPR) in the cycle ergometer, or treadmill time which are validated by regression calculations performed on specific populations.

Protocols for the assessment of functional capacity

Among the determinations performed in these ST, perhaps the most important is VO_2max, given that it is an indicator of the oxygen transport system and depends on the integrated functioning of the cardiovascular, respiratory and energy metabolic systems$_{39}$.

The protocols for assessing VO_2max should generally have a period of familiarization with the ergometer, a warm-up period (8-12 minutes) and small increases in workload, and should involve large muscle groups (> 50% of the total body muscle mass), being preferable the exercise to which the subject is more accustomed or is more comfortable to be able to make a maximum effort.

The objective of the test will determine the protocol to be used[35], so that the determination of thresholds by the ventilatory method requires a protocol in ramp or with short steps (not exceeding 1 min), since an approximately linear increase of the Variables that allow the analysis of slopes of ventilatory thresholds is needed.

The determination of a lactate curve requires a protocol of long stages (3-4 minutes) to reach the stable state in each load, which allows the stabilization of lactatemia in each intensity. If the test is done in atreadmill, pauses less than 1 minute must be taken to obtain the capillary samples, which means using a discontinuous protocol.

It is recommended not to change the protocol nor the conditions of realization of ST in the same athlete so that the results obtained in all of them can be compared. It is useful, at the beginning of the season, to perform an ST involving the largest possible number of muscle groups to check the limits of the cardiovascular and respiratory system, and to assess the maximum parameters of functional capacity. Subsequently, in the training period, it is more appropriate to perform evaluations in the laboratory by reproducing the sports gesture, combining them with specific tests such as field tests[39].

As an alternative to semi-plane protocols with preferred treadmill speed increments, the Bruce protocol or the Bruce protocol in ramp[42], or an incremental ramp-cycle ergometer test, are used in athletes with poor physical and obese status since are the more suitable protocols for them.

Treadmill protocols

The efforts that the athletes perform in some training and in most of the competitions are maximum, so that the ST in athletes, especially if they are of high level, must be maximum. It will be the athlete himself who finishes the test when he considers that he has reached his maximum effort and cannot go on. You will be allowed to grab and suspend from the sidebars of the rug, and lean with your feet on the side bands of the tape. From this moment, it will make a recovery walking at 4-5 km • h^{-1}.

There are many protocols for treadmill. Table 2 shows a maximum continuous progressive step test that is of great use in these athletes. Although tapestry tests are performed on athletes with a fixed gradient of 1%, in the later stages small slope increments can be used to ensure maximum effort.

The ramp protocols are used in the assessment of athletes and allow shortening the duration of the stages with minimum intensity increments[43,44]. These protocols have the advantages described in Table 3.

Table 3. Advantages offered by ramp protocols [39].

- Good biomechanical adaptation to the ergometer, limiting to the maximum sudden changes in the intensity of the load. The physiological and psychological adaptation is better than with protocols of stages of 1 to 3 minutes.
- Decreased risk of falls and injuries.
- Allows to calculate the increase of the load in an individualized way in test durations of 8-12 minutes. Therefore, they are useful for all types of populations (athletes of any level, sedentary, children, elderly, sick, obese, disabled, etc.).
- They are reliable and comfortable protocols, with a short duration and good adaptation of the subject.
- They allow to determinate the maximum levels of effort (VO_2, FC and VE, between other variables).
- Ease of determination of the submaximal parameters of effort (aerobic and anaerobic thresholds by ventilatory method), since it is a continuous protocol (without pauses between stages) and in which there is no abrupt changes in respiratory gas exchange.

Although the ramp protocols do not obtain stable states, maximum and submaximal parameters are obtained similar to those determined in incremental ramp and staggered protocols.

Their limitations are that they require very precise ergometers that are not available in many laboratories.

A protocol model used to assess high-level athletes consists of increments of 0.25 km • h^{-1} treadmill speed every 15 seconds. The slope remains constant at 1% and is increased by 0.25% every 15 seconds from the 13th minute of exercise. The initial speed is 6 km / h in women and 8 km / h in men[39].

Protocols on cycle ergometer

They are used in cycling and triathlon sports and in situations where there is difficulty in using the treadmill, such as balance disturbances and orthopedic limitations. They are also used when BP is more accurately controlled, or even to have a better electrocardiographic record[3].

Table 2. Treadmill stress protocol. Continuous incremental maximum test. 1%, 6-8 km x h^{-1} + 1 km x h^{-1} every minute. Sports medicine center. Top sports council [39].

Stage	Warming	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Speed	M.4	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
km × h^{-1}	V.6	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Slope (%)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	3	4
Time (min)	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

ST on a cycle ergometer has important limitations, such as its discomfort (although there are devices that allow the use of the athlete's bicycle) and that cause fatigue of the knee extensor muscles in non-experienced athletes, which limits tolerance to the test and with certain frequency leads to the termination of this before reaching the VO_2max. Values might be 10-20% lower than those that would be obtained between those who are and those who are not accustomed to ST in cycloergometer[45].

There are ST protocols designed to reproduce the conditions of the competition according to the duration, intensity and ergometer, and thus to be able to assess the maximum maximum effort parameters of each athlete in his specific test.

Examples of this type of test are those that simulate the competition of canoeing of 500 and 1,000 meters. They are tests of 2 and 4 minutes, respectively, in kayak-ergometer. In rowing simulates the competition of 2,000 meters, in a test of 6 minutes. All these tests are performed at maximum intensity, with free heating. In addition to the maximum parameters of effort, in this type of test the recovery period is evaluated. The limitation of these protocols is that submaximal stress parameters are not evaluated.

There are protocols for submaximal incremental aerobic ST for indirect assessment of VO_2max, which are used in case of no gas analyzer or because a direct evaluation of VO_2max is not necessary (for example, in amateur, leisure or recreational sportsmen). They are based on the linear relationship that exists between the HR and the workload, which allows to calculate indirectly the VO_2max by applying the nomogram of Astrand or by means of estimation formulas. They are physical work capacity evaluation tests and are performed to fixed PWCs, such as PWC-170, PWC-150 and PWC-130 (physical work capacity at 170, 150 and 130 bpm), useful for assessing the evolution of the physical fitness level following a training program and for health control.

Stable state stress protocols are used to assess the response of physiological parameters to submaximal loads that use constant intensities of long-term constant work (at least 15-20 min). They are useful in endurance sports and are used to focus on AT level. In these tests, the maximum intensity of work that can be performed in a condition of metabolic stability during a long-term exercise is sought and are useful as a performance evaluation in long duration sports[39].

Bank protocols

Test of the stairs of Margaria-Kalamen

It is a test designed to measure maximum anaerobic power[46].

A 12-step stairway of about 17.5 cm in height is required (Figure 3). The starting point is marked 6 meters before the first step and the test requires the subject to raise the steps three at a time (from step 3 to step 9) at the highest possible speed. Repeat three times and note the best time.

The developed power is calculated by the formula:

$$\text{Power (kg m / s)} = [M \cdot d] \div t$$

Figure 3. Schematic of the step used for the Margaria-Kalamen test.

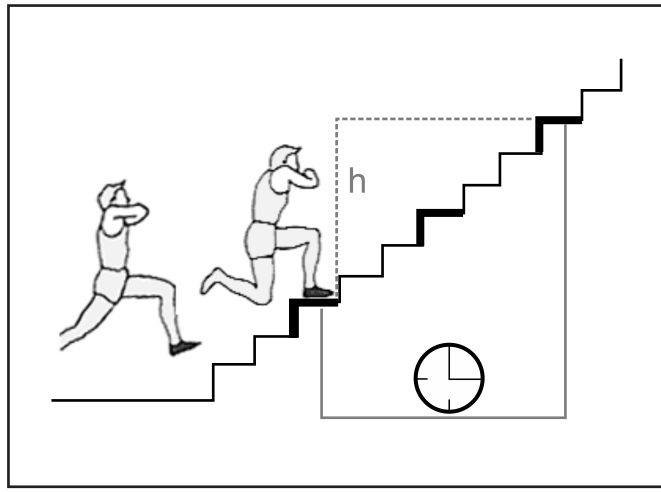


Table 4. Classification of the Margaria-Kalamen test results.

Men (kg m/s)	15-20 years	20-30 years	30-40 years	40-50 years	>50 years
Low	<113	<106	<85	<65	<50
Regular	113-149	106-139	85-111	65-84	50-65
Medium	150-187	140-175	112-140	85-105	66-82
Good	188-224	176-210	141-168	106-125	83-98
Excellent	>224	>210	>168	>125	>98
Women (kg m/s)	**15-20 years**	**20-30 years**	**30-40 years**	**40-50 years**	**>50 years**
Low	<92	<85	<65	>50	<38
Regular	92-120	85-111	65-84	50-65	38-41
Medium	121-151	112-140	85-105	66-82	49-61
Good	152-182	141-168	106-125	83-98	62-75
Excellent	>182	>168	>125	>98	>75

Where M is the body weight in kilos, d is the vertical distance between steps 3 and 9 (measure the height of a step and multiply by 6 and t is the time in hundredths of a second.

The test is assessed according to the classification shown in Table 4.

Test in Astrand Bank

It is submaximal test to calculate maximum aerobic capacity. It has the advantages of its low cost and its possibility of application to large population groups.

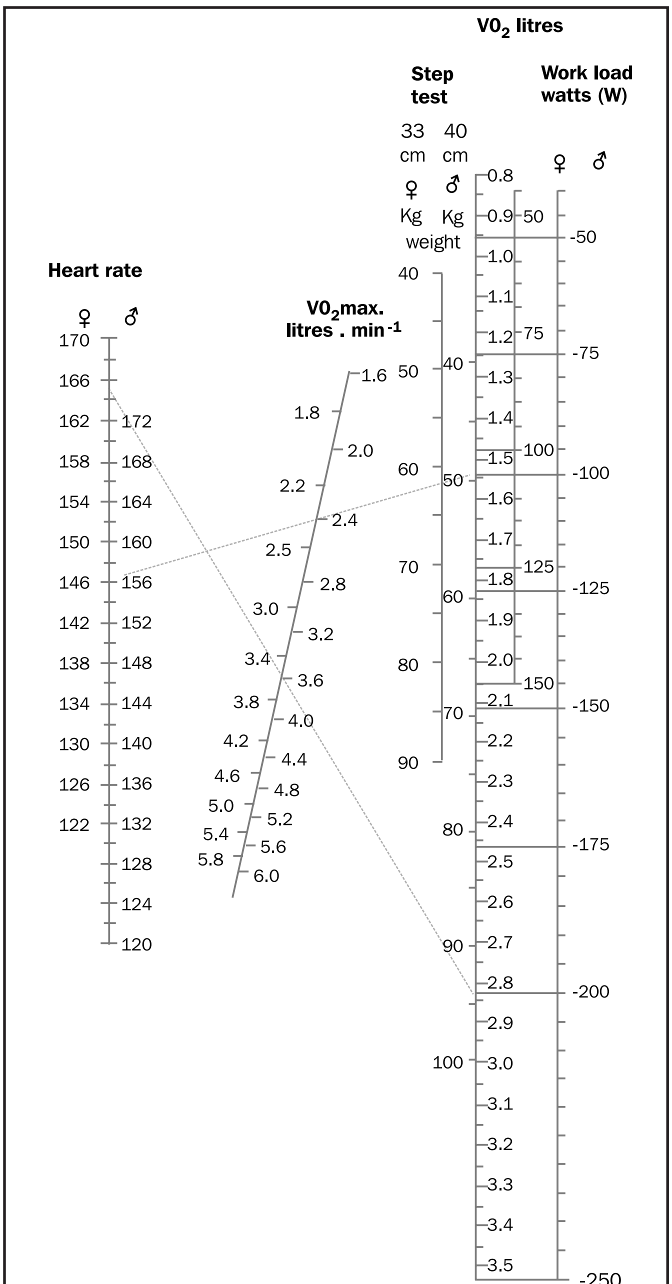
A 40 cm bench is used for men of more than 1.50 m of stature and 33 cm for women and men less than 1.50 m.

The individual must go up and down the bank at a rate of 22.5 climbs per minute. HR is measured at the end of the test and the VO_2max is calculated using the Astrand-Ryhming[47] nomogram (Figure 4).

Protocols for health control

Although one of the first studies carried out on ST in 1918 studied BP as an indicator of cardiac efficiency[48], the first use of ST as a diagnostic and assessment tool for ischemic heart disease has been consolidated since the late 1940s[49]. Currently, the applications of ST are greater, and in SM they are used in the health control of various pathologies (hypertension, exercise-induced asthma, arrhythmias induced by specific efforts ...), for risk stratification, for effectiveness control of some medications and for prescription of exercise, among other indications.

Figure 4. Astrand-Ryhming nanogram[47].



Protocols of stress tests in children

Although the criteria for choosing ST protocol in children are comparable to those of adults, an adjustment should be made based on the child's size, age and physical condition[50,51].

The duration of the test should not be long and it must be programmed to last between 8 and 12 minutes. In this way, the child is not bored or discouraged. In addition, in treadmill protocols, high speeds should be avoided so as not to limit children who have a small stride[52], and it is advisable to increase only speed or slope using small increments of load in any case.

The ST running on a treadmill and ramp protocols are a good option in the pediatric population, while ST in cycle ergometer in young children are not recommended because they find it difficult to maintain a constant pedaling rate.

The proposed protocols for cycloergometry in children and adolescents are continuous type incrementals[53], using load increments of 0.025 W / kg every 6 seconds, or 0.5 W / kg every 2 minutes, starting from an initial load of 0- 0.5 W / kg.

The protocols that are most used on treadmill in children are Bruce and modified Balke protocols[39]. In the latter the speed is maintained and only the slope is modified. For children in good physical condition, it is best to keep the slope steady and increase speed[54].

In children whose exercise tolerance is limited, protocols with slower load increments are used, which allows the assessment of the pre-exhaustion response, such as the McMaster (on cycle ergometer) and the modified Balke (treadmill) (Table 5).

Table 5. Effort protocols in children[39].

McMaster test for the cicloergometer				
Size (cm)	**Initial load (w)**	**ΔW**	**Cycling rhythm (rpm)**	**Time (min)**
<120	12.5	12.5	50	2
120-139.9	12.5	25		2
140-159.9	25	25		2
>160	25	50(♂)-25(♀)		2
Modified Balke test for treadmill				
Subject	**Speed (km × h⁻¹)**	**Initial slope (%)**	**Δ slope (%)**	**Time (min)**
Limited physical condition	4.8	6	2	2
Sedentary	5.2	6	2	2
Active	8	0	2.5	2
Athlete	8.4	0	2.5	2

Stress test protocols in the elderly

The choice of protocol in the elderly depends on the individual's physical state. If their physical condition is good, it's healthy and does sports, there are no limitations to perform maximum tests on treadmill and cycle ergometer. In elderly people with poor coordination, stability and balance, to avoid falls and to make the test easier to perform, it is advisable to use the cycle ergometer. As there is no ideal protocol for this population group, ST should be individualized according to the characteristics of age and physical condition. The most widely used protocols in the elderly are Balke's and the modified Naugthon treadmill, but the important thing is to increase the slope before the speed to march for most of the test. In cycloergometer, the most used protocols are ramp protocols.

Stress test protocols in athletes with disabilities

In athletes with physical disabilities, ergometers adapted to the situation of the individual must be used. The visually impaired can perform ST without great difficulty, both in treadmill and cycle ergometer depending on their sport specialty. Rubbing or occasional contact with the side and front ribbons of the treadmill serves them as a reference, but the blind often need to make the treadmill ST attached to one of the sidebars. Apart from these observations, the protocols are similar to those used for non-blind.

Wheelchair athletes perform ST on an arm ergometer (the most used is the crank ergometer) or in their own wheelchair on an adapted treadmill, with ramp or staggered protocols with variable increments of the load[55].

In sportsmen with physical and mental disabilities, safety measures must be taken to avoid accidents, and an effort must be made to ensure that the athlete conforms to the protocol, the ergometer and laboratory conditions[39].

Frequently used protocols in the laboratory

Discontinuous test with long steps

Ergometer	Treadmill.
Rest	1 minute record.
Warm up	3 minutes at 8 km / h (men) or 7 km / h (women).
Start test	8 km / h (women) or 9 km / h (men).
Increments	2 km / h every 3, 5 or 4 minutes (see comments).
Recovery	Keep the gas register until: 1) VO_2 decrease stabilizes, or 2) the HR reaches 120, or 3) the RER begins to descend. Determine the lactate in minutes 1, 3, 5, 8 and 12.
Observations	The steps are 3 minutes of running and 0.5-1 minutes of stopping for sampling.

This test is useful for the realization of lactate curves in treadmill.

Continuous test with long steps

Ergometer	Cycle.
Rest	1 minute record.
Warm up	3 minutes at 50 W, free cadence.
Start test	75 or 100 W (according to level).
Increments	25 or 50 W (depending on level) every 3 or 4 minutes
Recovery	Keep the gas register until: 1) VO^2 decrease stabilizes, or 2) the HR reaches 120, or 3) the RER begins to descend. Determine the lactate in minutes 1, 3, 5, 8 and 12.
Observations	Lactate samples are taken in the last 30 seconds of each step, in the lobe of the Ear, without stopping the test.

This test is useful for the realization of lactate curves in cycle ergometer.

Continuous test with short steps

Ergometer	Cycle.
Rest	1 minute register.
Warm up	3 minutes at 50 W, free cadence.
Start test	75 or 100 W (according to level).
Increments	25 or 50 W (depending on level) every minute.
Recovery	Keep the gas register until: 1) VO^2 decrease stabilizes, or 2) the HR reaches 120, or 3) the RER begins to descend.

This test is useful for the determination of ventilatory thresholds on a cycle ergometer.

Continuous test with short steps

Ergometer	Treadmill.
Rest	1 minute register.
Warm up	3 minutes at 8 km / h (men) or 7 km / h (women).
Start test	9 km / h (men) or 8 km / h (women).
Increments	1 km / h every minute.
Recovery	Keep the gas register until: 1) VO_2 decrease stabilizes, or 2) the HR reaches 120, or 3) the RER begins to descend.

This test is useful for the determination of ventilatory thresholds in tapestry.

Continuous ramp test of 25 W

Ergometer	Cycle.
Rest	1 minute register.
Warm up	3 minutes at 50 W, free cadence.
Start test	50 W.
Increments	25 W every minute (5 W every 12 s).
Recovery	Keep the gas register until: 1) VO_2 decrease stabilizes, or 2) the HR reaches 120, or 3) the RER begins to descend.
Observations	Ramp indicated in women and cyclists with little shape. The pedaling cadence is free, but should be maintained above 60 rpm.

30 W continuous ramp test

Ergometer	Cycle.
Rest	1 minute recording.
Warm up	3 minutes at 50 W, free cadence.

Start test 50 W.
Increments 30 W every minute (10 W every 20 s or 5 W every 10 s).
Recovery Keep the gas register until: 1) VO^2 decrease stabilizes, or 2) the HR reaches 120, or 3) the RER begins to descend.
Observations The pedaling cadence is free, but should be maintained above 60 rpm.

Continuous ramp test of 35 W

Ergometer Cycle.
Rest 1 minute recording.
Warm up 3 minutes at 50 W, free cadence.
Start test 50 W.
Increments 35 W every minute (12 W every 20 s).
Recovery Keep the gas register until: 1) VO_2 decrease stabilizes, or 2) the HR reaches 120, or 3) the RER begins to descend.
Observations Only for high level cyclists. The pedaling cadence is free, but should be maintained above 60 rpm.

These ramp tests are especially useful for the determination of ventilatory thresholds on a cycle ergometer. They are of choice in sportsmen with good adaptation to the bicycle.

Wingate test

Ergometer Mechanical cycle (Monark).
Warm up 3 to 5 minutes.
Load Male: 75 g / kg body weight.
Women: 45 g / kg body weight.
Performance Pedaling at the highest possible speed during 30 seconds, picking the rpm every 5 seconds.
Observations Perform on a different day the stress test. If it's in the same day, perform first this test and leave at least 30 minutes between both tests.

Wingate Arm Test

Ergometer Arms ergometer (Monark).
Warm up Free, 3 to 5 minutes.
Load 0.005 kg / kg of weight.
Performance Turn the crank with the arms to the maximum speed possible for 30 seconds, recording the bpm every 5 seconds.

The loads to be applied are specified in Table 6.

This test is still used today, although some modifications have been proposed[56,57].

The Wingate test is of choice for the evaluation of lactic anaerobic metabolism (potency, capacity and resistance) in cycloergometer.

Maximal Accumulated Oxygen Deficit (MAOD)

Ergometer Treadmill.
Day 1 Determine the VO_2max by incremental test.
Day 2 Determine the Running Economy Equation (X = vel; $y = VO_2$) by:
Method A: eight submaximal loads ranging from 35% to 100% of VO^2max, with a duration between 5 and 10 minutes (equal to all) and a slope of the treadmill of 10.5%.
Method B (simplified): two submaximal loads (one <85% VO_2max and another> 85% VO_2max) with a duration of 10 minutes and a slope of the treadmill of 10.5%.
Day 3 Supramaximal test at an equivalent intensity to 140% of the speed at which the VO_2max is obtained on the economy line, till the exhaustion (2-4 min). It is estimated in the straight line O_2 demand for that intensity and multiplies for the duration of the test in minutes (demand accumulated O_2). The difference between this and the Cumulative consumption of O_2 is the MOAD (ml/ kg).

Table 6. Loads to be applied in the Wingate test (legs and arms).

Body weight	Leg	Arm
20.0-24.9	1.75	1.25
25.0-29.9	2.0	1.5
30.0-34.9	2.5	1.75
35.0-39.9	3.0	2.00
40.0-44.9	3.25	2.25
45.0-49.9	3.5	2.5
50.0-54.9	4.0	2.75
55.0-59.9	4.25	3.0
60.0-64.9	4.75	3.25
65.0-69.9	5.0	3.5
70.0-74.9	5.5	3.95
75.0-79.9	5.75	4.0
80.0-84.9	6.25	4.25
85.0	6.50	4.5

This is a very useful test to evaluate the contribution of anaerobic metabolism in supramaximal tests. It is especially indicated for the evaluation of sprinters, although it is little used because of the complexity of its accomplishment.

Clinical test on cycle ergometer

Ergometer Cycle.
Rest 1 minute register.
Warm up No load, 3 minutes, free speed and with no connection to gasses
Start test 25 or 50 W (depending on the capacity of the subject).
Increment Between 10 and 25 W (depending on the capacity of the subject) with intervals of 1-3 minutes.
Recovery Keep the gas register until: 1) VO_2 decrease stabilizes, or 2) the HR reaches 120, or 3) the RER begins to descend.
Observations Indicated for ECG and BP monitoring. The pedaling cadence is free, but must be kept above 60 rpm

Ventilatory provocation test

Ergometer	Cycle or treadmill.
Rest	Perform basal spirometry.
Test	Increase intensity bit by bit till reaching a ventilation between the 60% and the 70% of the maximum (calculated as FEV1 × 35), and maintain this load for at least 6 minutes. If ventilation is not available, maintain for 10 minutes an intensity of 70% of their VO_2max (or its HRmax).
Observations	Indicated for the diagnosis of exercise induced bronchoconstriction. Perform an spirometry after 5, 10, 20 and 30 minutes after the end of the test.

Bruce's Test

Ergometer Treadmill.
Rest 1 minute register.
Duration of the load 3 minutes.

Load	Speed (km/h)	Slope (%)
Warm up	1,6	0
1	2,7	10
2	4	12
3	5,4	14
4	6,7	16
5	8	18
6	8,8	20
7	9,6	22
Recovery	2,4	0

Modified Bruce test

Ergometer Treadmill
Rest 1 minute register.
Duration of the load 3 minutes

Load	Speed (km/h)	Slope (%)
Warm up	1,6	0
1/2	2,7	5
1	2,7	10
2	4	12
3	5,4	14
4	6,7	16
5	8	18
6	8,8	20
7	9,6	22
Recovery	2,4	0

The Bruce protocol has advantages such as its great utilization, which allows very accurate comparisons. In addition, the 3 minutes of each step allow the acquisition of data, although the high increases in load between stages have a weak relationship between VO_2 and workload, and that the fourth step can be done running or walking, which results in different consumptions of oxygen.

Choosing the protocol

The ST is a medical act with diagnostic purpose, both clinical and functional, and that is why the best protocol must be chosen to achieve the highest sensitivity and the highest reliability of the information obtained.

First, the choice is made according to the characteristic of the test: whether it is exclusively clinical test, looking for confirmation of some pathological suspicion, or if it is a functional test, that seeks a functional assessment of sports training. In the latter case, sometimes the protocol is not standard, but more specific depending on the practiced sport.

Second, the protocol is chosen depending on whether it is a child, an adult, an elderly person or a disabled person.

Third, it is necessary to decide whether to perform a test with respiratory gas analysis (direct) or without such analysis (indirect).

In general, the ergometer to be used will be the treadmill by default, although according to various circumstances, as if the patient has problems of the locomotor apparatus, or in the case of a cyclist, or a person with lower train disability, the cycle ergometer will be used, the crank ergometer or other more specific. In children, the protocol should not exceed 8-12 minutes in duration.

If the treadmill is used, the choice of protocol will depend on the size of the child. For example, children under 8 years of age may have difficulty adapting for speed increases above 3 km/h, so progressive and uniform increases in speed and slope1 are recommended, but not simultaneously. If the objective is clinical, the Bruce or the adapted Bruce58 protocol is preferably used, although Balke may be used, which maintains a constant speed increasing the slope, or the modified Balke, in which speed is related with training level, age and body size. In the case of functional tests, a 3% steady slope run protocol is recommended with 0.5 km/h speed increments every minute, with the initial speed being 4 km/h[59].

In the cycleergometer, in clinical tests, a protocol with an initial load of 0.5-1 W/kg, with increments every 2-3 minutes, is used to perform correct electrocardiographic and BP measurements (protocol of James, Godfrey, PWC ...). If the target is functional, the increments will be every minute.

Many of the protocols used in children are conditioned to the body surface. Thus, the James protocol, which establishes work steps of 3 minutes duration, groups the subjects by body surface area. Godfrey's is similar, but the work steps are 1 minute and the children are grouped by height, while the Mc Master uses 2-3 minutes steps.

In very small children or with very low physical form a ramp protocol must be used, that is to say, without steps.

In adults, the ergometer used will be the one that best reproduces the type of exercise usually performed. It should be chosen between a direct test, with respiratory gas analysis, or an indirect test, in which the value of VO2max will be estimated according to the protocol used. The direct tests are used for functional tests and to evaluate cardiovascular or cardiac rehabilitation, mainly.

In the cycle ergometer, a lower VO_2max is obtained due to a lower cardiac output (for a smaller systolic volume), which according to some authors is estimated between 6% and 20% 60, while it does not differ between continuous and discontinuous tests, although continuous tests are recommended.

In the treadmill, grasping the safety support can mean a difference in energy expenditure of up to 30%[2,60].

If an ergospirometry is performed, the tests will be continuous, with incremental load and until the exhaustion. The increments must be intermediate for a duration of the test of 8-17 minutes, since with increments below or above the VO_2max obtained is lower[1].

In indirect tests, VO_2 is overestimated in protocols with large work increments, and the variation of the VO_2 estimation in relation to the load is much higher in the standardized tests than in the individual ramp tests.

In the treadmill clinical trials, the Bruce protocol should be used, the main objective of which is the diagnosis and evaluation of coronary heart disease[1]. In patients with lower functional capacity and older patients, the modified Bruce test (continuous incremental protocol with less intense work steps) is used. Other protocols, such as Balke, in which speed is constant and used in subjects with very low functional capacity, or Naughton, were designed for subjects with high coronary risk and low functional capacity; The latter two are also used for older patients[3]

In athletes, the protocol should be individualized, with a fixed slope at 1%, to simulate wind resistance, and in increments of 0.5-1 km/h every 30 seconds or every minute for an optimum duration of 8-12 minutes.

In a progressive and maximal test, the slope effect does not cause significant differences in VO_2 and HRmax, compared to protocols with no slope, although in protocols with slope the lactate after exertion is higher due to the muscular demands of the muscles[61].

No differences in VO_2max have been observed between triangular and rectangular protocol tests. Triangular tests are often used because of time savings.

The cycle ergometer is used in osteoarticular limitations, instability in the treadmill, coordination difficulties and when it is important to evaluate the behavior of the BP more accurately, or if a signal without ECG noise is required. It is the ergometer of choice in cyclists.

In mechanical cycle ergometers, cadences should be kept constant at around 60 rpm; in electromagnetic brakes it is advisable to maintain cadences of 70-90 rpm (depending on the training). No differences were found in cardiopulmonary variables between the ramp and stepped protocols[60].

In order to estimate the VO_2max in an indirect test, the PWC-170 is used, which evaluates the performance capacity from the cardiovascular point of view. It is recommended to use an initial power of 10 or 25 W, with increments of 25 W every 2-3 minutes, until reaching 170 bpm. In the disabled, with total disability of the lower train, a crank ergometer is used and an initial resistance of 5-10 W, in increments of 10-20 W, is recommended at a rate of 50-75 rpm[3].

Security

ST is a usually safe procedure, with minimal risk if the contraindications for its realization are rigorously respected.

Table 7. Possible complications of stress test.

Minor	Mayor
– Supraventricular arrhythmias – Inadequate chronotropic response (excessive or insufficient) – Contractile insufficiency of the left ventricle – Ventricular extrasystoles. – Congestive Heart Failure – Cerebral vascular ischemia – Arterial hypotension	– Supraventricular tachycardia associated with severe cardiopathy. – Ventricular tachycardia or ventricular fibrillation. – Acute stroke – Syncope – Myocardial infarction. – Death.

From a deontological point of view, ST contrary to the health of patients or athletes should be avoided, and must be performed in a way that adapts to the characteristics of these patients.

The risks of ST are related to the stress to which the heart is subject to. Ideally, and following criteria of clinical safety, possible complications are better controlled if ST is performed in a health center or clinic, in the presence of an experienced doctor and with the appropriate equipment to intervene in any eventuality.

It is considered that one death occurs per 10,000 ST and one serious complication per 1,000 tests performed (Table 7).

Even in cardiovascular patients, the risks of ST are minimal, with 0.05% morbidity and 0.02% mortality, 3.5 acute myocardial infarction (MI) and 48 severe arrhythmias per 10,000 ST[3].

More frequent is the appearance of supraventricular and ventricular arrhythmias, repolarization alterations that may or may not require other cardiological studies, such as echocardiograms, ECG-Holter or magnetic resonance imaging (MRI).

Extreme caution should be exercised in patients with impaired left ventricular function (a previous echocardiogram may be helpful), with alterations in repolarization and conduction disorders, as they are particularly at risk of triggering arrhythmogenic mechanisms during physical exertion.

ST is a simple resource, inexpensive and of an easy methodology and technical application, but this can be altered if it loses the rigor of its application and interpretation, turning into a technique of low reliability, low performance and high risk of complications.

Despite the correct choice of technique and its correct performance, there may be undesirable effects, both the common ones resulting from any intervention, and that can affect any organ or system, such as those due to the patient's vital situation (diabetes, heart disease, AHT, advanced age, anemia, obesity ...) and the specifics of the procedure.

The study of the morbimortality of ST in large series can be summarized as follows:

– Mortality of 2 / 100,000 and 96 serious complications, in particular ventricular fibrillation (VF), in 1,065,923 ergometry[62].

- Sixteen deaths in the week after the test, which may be attributable to the test, and 40 MI; One death and 2.4 MI per 10,000 ST in a series of 170,000 ST[63].
- Four deaths and 12 MI; One death and three MI per 28,000 ST in a series of 113,130 ST[64].

There is a work of 9,464 ST without deaths, which the authors attribute to a careful selection of patients and to the conclusion of the test at the appropriate time[65].

Apart from the serious complications mentioned, it is relatively frequent to present a vasovagal syndrome at the end of the effort, which is benign and usually resolved spontaneously, the incidence of which can be minimized by an active and progressive recovery after exertion. Susceptibility to post-exertional syncope has been estimated in 50-80% of healthy individuals on post-strength tilt test[18].

Although more and more ST are being performed by sports doctors, cardiologists or pulmonologists, serious incidents recorded have not increased. This has contributed to the progress in the detection of contraindications, in the previous assessment and in the management of the patients, in the ergometry methodology and in the knowledge and application of the CPR measures.

Emergency equipment and protocols

The medical staff responsible for the implementation of ST must have the appropriate equipment to deal with emergencies related to ST, as well as adequate protocols for their management. In order to avoid, as far as possible, the occurrence of situations that may constitute a risk for the athlete or patient who is going to perform an ST, the sports doctor must assess, through careful history, a complete physical examination, the taking of the BP and performance of a resting ECG, whether or not there are contraindications for the performance of ST.

In addition, in an ST, complications may appear that require the presence of a doctor and a CPR team. In fact, the possible risks derived from ST make insurance companies place it at the highest risk level (along with cardiovascular surgery and neurosurgery) when inscribing liability insurance for the professionals who perform it.

Performing ST with gas and ventilation record or ergospirometry allows more information on the biological status of people, which increases the need for biomedical knowledge about what is being measured.

Therefore, laboratory STs should always be performed by (or in the presence of) a doctor with the appropriate training (SM specialist, cardiology or pulmonology), and always with the means to address potential complications with vital commitment. Table 8 shows the key points regarding security in the ST.

The ergometry room must be in a place of easy access, with possibility of rapid evacuation in emergency situations, and must be equipped with a communication system (alarm, intercom, telephone) to be able to quickly report serious situations.

The material needed for the emergency protocols includes stretcher, oxygen take or bottle, complete resuscitation equipment and adapted to the characteristics of the possible athletes susceptible of valuation and that allows the venous approach, the aspiration of the digestive and aerial routes, the tracheal intubation and mechanical ventilation, cardiac defibrillation and drugs and solutions (volumetric and energetic replacement) required for resuscitation. (See Annex 1.1 and Annex 1.2.)

Table 8. Stress test safety.

- To know the magnitude and frequency of possible physical and psychological risks.
- To classify athletes to be evaluated according to the individual characteristics and the limits of each one (anamnesis, physical examination and rest ECG, sports level and objectives), never ceasing to be realistic.
- To know and apply the criteria for completing the test.
- Know, dominate and apply the procedures of urgency and reanimation, and to realize a continuous formation of the same ones.
- Liability insurance of the professionals who perform it.
- To establish a rapid intervention plan, which also includes important telephone numbers.
- To use informed consent forms.

The CPR device must be sealed, with the entry of the seal number in a log book. The correct functioning of the defibrillator should be checked every day, and a monthly review of the expiration of the medication.

Informed consent

The practice of medicine has undergone notable changes in the doctor-patient relationship: the doctor's paternalistic attitude in the XX century has been replaced by the patient's right to be informed of his pathological process and to participate decisively in its management, with the respect of the doctor in the decisions taken freely and voluntarily by the patient[66,67].

The patient has the right to know all the information of any action in the field of his health that is going to be performed, and the doctor has the obligation to inform him of the exploration, diagnosis or treatment advised.

Performing an ST requires informed consent from the patient or athlete.

Informed consent is the explanation given to a patient, attentive and mentally competent, of the nature of his illness, as well as the balance between the effects of this and the risks and benefits of the recommended therapeutic procedures, to then request his approval to undergo such procedures. The presentation of the information to the patient must be understandable, unbiased and sufficient so that it can be understood; Patient collaboration must be achieved without coercion; In addition, the doctor should not take advantage of their potential psychological dominance over the patient[68]. This procedure is also applicable to healthy people, as is the case of athletes.

The information, which as a general rule will be provided verbally and recorded in the medical record through the signature of the interested party of the informed consent document, comprises at least the purpose and nature of each intervention, its risks, the foreseeable consequences if it is not carried out the proposed treatment, the direct or indirect consequences of the intervention[69], and the possible complications.

The clinical information will be true, it will be communicated to the patient in an understandable and appropriate way to his needs, and will help him to make decisions according to his own free will[70].

The Law regulating the autonomy of the patient and of rights and obligations in the field of information and clinical documentation[71] establishes the obligation to obtain the free and voluntary consent of the affected person once he receives the information mentioned in writing, because ST is a diagnostic procedure which involves risks or inconveniences of notorious and predictable negative repercussion on the health of the subject.

Lack of information by the doctor, at least in surgical procedures, can be punished as a crime of injury or coercion, and can lead to significant penalties.

Consent is freely revocable by expressing it on a document at any time, including in research studies[72].

Table 9 shows the contents of informed consent, which should be stated in a brief manner and in understandable language so that the medical concepts can be understood by the generality of the users.

The consent holder is the person of legal age (16 years or more) with full capacity. In the minors, it corresponds to the parents or guardians. The consent is temporary and revocable, without subjection or formality, and therefore must be rendered before the medical-surgical act and must subsist throughout the procedure or treatment.

Given that, in SM, a good part of the work is done in minors, you must keep in mind the consent by representation, whose regulation establishes the following assumptions:

- When the patient is unable to make decisions, at the discretion of the attending doctor, or his physical or mental state does not allow him to take charge of his situation. If the patient does not have a legal representative, the consent will be provided by persons related to him for family or de facto reasons.
- When the patient is legally incapacitated.
- When the minor patient is not able, intellectually or emotionally, to understand the scope of the intervention. In this case, the consent will be given by the legal representative of the child after having heard his opinion if he is 12 years old. In the case of children who are not incapacitated or incapacitated, but emancipated or 16 years of age, consent cannot be given by representation. However, in case of serious risk action, according to the optional criteria, the parents will be informed and their opinion will be taken into account for the corresponding decision.

Annex 1.3 describes informed consent documents for ST in SM.

Table 9. Contents and sections to be included in the informed consent document.

- Patients personal information.
- Name and surname of the doctor that informs. It doesn't have to be the same doctor that it's going to perform the procedure that has been consented
- Name of the procedure to perform, with a brief and simple explanation of the objective of the procedure, what is the procedure about and the way in which it's going to be done.
- Description of the safe consequences of the intervention that should be considered relevant or important.
- Description of the typical procedure risks. These should be considered as those whose appearance must be expected under normal conditions, according to experience and the current state of science. Also included are those that are infrequent, but not exceptional, and are considered very serious.
- Description of personalized risks, which are those related to the personal circumstances of patients and refer to the previous state of health, age, profession, beliefs, values and attitudes of patients, or any other circumstances of a similar nature.
- At the facultative discretion, information referring to the probable discomfort of the procedure and its consequences may be included.
- Patients statement to have received information that regarding the extremes indicated in the previous sections, as well as alternatives to the procedure, with pros and cons, how the patient participates, if desired, in choosing the most appropriate, and that such choice takes their preferences into account.
- Patients manifestation of being satisfied with the information received and having obtained information on the doubts raised and on the possibility of revoking at any time informed consent, without expression of cause, as well as the expression of his consent to undergo the procedure .
- Date and signatures of the reporting doctor and patient.
- Section for consent through legal representative in case of patient incapacity.
- Section for the consent revocation, which should be included in the document itself.

Procedure for performing the stress test

Indications of the stress test in sports medicine

Indications for performing ST in SM are several, as will be described below, but can be summarized in three main sections: diagnosis, prognosis and assessment of functional capacity[20].

Indications of achievement of ST, according to the scientific evidence regarding its usefulness and effectiveness[1,3,6,20], are:

- *Type I* (there is evidence and / or general agreement that the procedure or treatment is useful and effective):
  - Assessment of athletes with suspected heart disease.

- Assessment of athletes with diagnosed heart disease, as an indication of fitness for sports practice.
- Athletes with basal electrocardiographic alterations in order to establish their relationship with physical training.
- Evaluation of functional capacity in competition athletes, prescription of workloads and assessment of progression after a physical training program.
- Sportsmen with suspected exercise-induced asthma.

– *Type IIa* (weight of evidence / opinion is in favor of utility / effectiveness):
  - Asymptomatic athletes, over 35 years old and with two or more risk factors, as an assessment of fitness for sports practice.
  - Asymptomatic athletes under the age of 35 with a family history of unexplained sudden death related to exercise in young first-degree relatives.

– *Type IIb* (utility/effectiveness is less substantiated by evidence / opinion):
  - Orientation on the rhythm of competition in athletes who prepare a long duration test.

– *Type III* (there is evidence or general agreement that the procedure or treatment are not useful or effective, and in some cases can be dangerous):

Sportsmen under 35 years for heart disease detection.

They are specific indications of ST in sportsmen, to evaluate the responses and adaptations of the body trained by exercise, and to obtain data on the effects of training and sports performance[39], the following:

- Determination of physical performance capability.
- Prescription of the intensity of the training loads in sportsmen of any level, especially in the high level for the improvement of the sport performance.
- Evolutionary control of the parameters of maximum and submaximal effort.
- Adjusting of the competition pace in long-term events.
- Low performance rating.
- Study and follow-up of athletes with cardiopathies that do not initially impede the performance of physical exercise.
- Evolution and behavior in exercise of electrocardiographic changes in rest typical of the athlete.
- Recognition of fitness for sports practice.

The inclusion of a submaximal or maximal ST has been considered necessary in any type of medical examination for sports aptitude, specifically at least one ST in Astrand bench in basic examinations, recommended in federated and compulsory sport in national and international competition athletes[73,74].

In addition, it is advisable to perform an ST prior to the beginning of vigorous physical training in most chronic diseases, but especially in the following situations and pathologies:

- Symptoms of onset or instability of cardiovascular disease (CVD).
- Diabetics with at least one of the following factors:
  - > 35 years of age.
  - Diabetes *mellitus* type 2 of more than 10 years of evolution.
  - Diabetes *mellitus* type 1 with more than 15 years of evolution.
  - Hypercholesterolemia (plasma cholesterol> 240 mg/l).
  - AHT.
  - Smoking habit.
  - Family history of ischemic heart disease in first-degree relatives <60 years of age.
  - Microvascular disease.
  - Peripheral arterial disease.
  - Autonomic neuropathy.
  - Final stage of chronic kidney disease.
  - Pulmonary disease: chronic obstructive pulmonary disease (COPD), asthma, interstitial lung disease or cystic fibrosis.

Contraindications of exercise test in sports medicine

The contraindications of the ST (Table 10) are classified as absolute (imply the impossibility of carrying out the ST) and relative (implying an individualized assessment by the practitioner on the appropriateness of its realization, considering the pros and cons of its realization for the athlete or patient).

Table 10. Contraindications of stress test in sports medicine[1,3].

Absolute

- Recent myocardial infarction (less than 3 days).
- Unstable angina not stabilized with medication.
- Uncontrolled cardiac arrhythmias that cause hemodynamic deterioration.
- Active endocarditis.
- Severe aortic stenosis.
- Unstable heart failure.
- Pulmonary embolism.
- Pericarditis or acute myocarditis.
- Aortic dissection
- Physical or psychological incapacity to perform the test.

Relative

- Obstruction of the main left coronary artery.
- Moderate valvular stenosis.
- Severe arterial hypertension (SBP> 200 or DBP 110 mmHg)
- Pathological tachyarrhythmias or bradyarrhythmias.
- Hypertrophic cardiomyopathy or other forms of left ventricular outflow tract obstruction.
- Second degree atrioventricular block (Mobitz II) or third degree.
- Recent Stroke
- Undiagnosed syncope
- Mentally handicapped with limited ability to collaborate.
- Uncorrected or decompensated medical condition, such as anemia, electrolyte disturbance, diabetes or hyperthyroidism.
- Recent or recovering sports injury

Stress test stopping criteria

The decision to stop an ST is an important element to be taken into account during its supervision, which will depend, among other factors, on the objective of the test and on the individual situation[1].

There are absolute criteria, whose presence will imply the incontrovertible stopping of the stress test, and relative, in which it will be necessary to evaluate the relationship between the risk of continuing the test and the benefit that its achievement could provide. Absolute and relative criteria are described in Tables 11 and 12.

Preparation of the subject

Following strict and correct instructions for the preparation of the subject allows to obtain ST data in better conditions, so they should follow the recommendations described in Table 13[1,3].

Preparation of exercise electrocardiogram

Preparation of the skin

An important factor that determines the quality of an effort electrocardiographic record is the contact surface between the electrodes and the skin. Careful preparation of the skin is necessary in order to obtain a quality ECG[1]. The areas where the electrodes are applied should first be shaved, and then rubbed with a gauze soaked in alcohol for a proper degreasing. Once the skin is dry, proceed to scrape the areas marked with fine sandpaper or any other abrasive means. Applying these procedures achieves a reduction of skin resistance to 5000 ohms, which will contribute significantly to an improvement in the quality of the record.

Table 11. Absolute criteria for stopping the stress test[1,3,6].

- Reiterated desire of the subject to suspend or stop the test.
- Progressive, moderate to severe anginal thoracic pain (grade 2-3).
- Failure to increase systolic pressure despite increasing load.
- Decrease of systolic pressure of more than 10 mmHg with respect to the basal one, in spite of increasing the intensity of the effort, when accompanied by other evidence of ischemia.
- Technical difficulties that prevent the correct monitoring of blood pressure.
- Bad electrocardiographic signal, or that prevents the correct control of tracing.
- Apparition of severe / malignant arrhythmias: tachycardic atrial fibrillation, frequent progressive and multiform ventricular extrasystoles, ventricular tachycardia, sustained ventricular tachycardia, flutter or ventricular fibrillation; Second or third degree atrioventricular block affecting cardiac output during exercise.
- Symptoms of the central nervous system, such as dizziness, presyncope, syncope, ataxia.
- Signs of poor perfusion: cyanosis, pallor.
- ST segment elevation (≥1.0 mm) in leads in which there is a Q wave due to previous myocardial infarction (in others other than aVR, aVL and V1).

Table 12. Relative criteria for stopping the stress test[1,3,6].

- Persistent decrease in systolic pressure ≥ 10 mmHg with respect to the basal, despite increasing effort intensity, without the need to be accompanied by other evidences of ischemia.
- ST segment changes: horizontal or descending depression of more than 2 mm, measured between 60 and 80 ms after the J point, in patients with suspected angina.
- Striking changes of the QRS complex: marked change of its axis.
- Arrhythmias other than ventricular tachycardia, such as non-severe tachycardias or minor arrhythmias: multifocal ectopy, ventricular triplets, supraventricular tachycardia, bradyarrhythmias with the possibility of evolving to more complex arrhythmias or interfering with hemodynamic stability, cardiac block.
- Blockages or intraventricular conduction retardation induced by exercise that cannot be immediately distinguished from ventricular tachycardia or that simulate ventricular tachycardia.
- Fatigue, shortness of breath, wheezing. Cramping or claudication of lower limbs.
- Progressive chest pain.
- Hypertensive hemodynamic response: systolic> 250 mmHf and diastolic> 115 mmHG

Electrodes and cables

The disposable electrodes used in the stress tests must have a high quality and reliable sensor in the register, which has a silver / silver chloride layer, regulated according to ANSI/AAMI EC12 or similar, impregnated in an adhesive gel. Contact between the electrodes and the skin generally improves after several minutes from application and with the moisture generated during exercise through sweating, although excessive sweating can worsen contact between the two surfaces (skin-electrode).

In order to reduce the interference or noise generated by the movement of the electrodes and cables, it is convenient to place an elastic mesh fitted to the chest, in the form of a T-shirt, especially in obese patients[3]. In women with excessive breast size artifacts, noise compensation is sometimes required at the expense of varying the location of the electrodes.

The connection cables between the electrodes and the recording device must be light, flexible and properly protected. Usually, the cables are designed to reduce artifacts due to movement during the test, by digitizing the electrocardiographic wave into the recorder, generally adapted to the body. Cables usually have a half-life of 1 year and must be replaced periodically to reduce electrical interference. There are

Table 13. Recommendations for the preparation of the subject for the stress test[1,3].

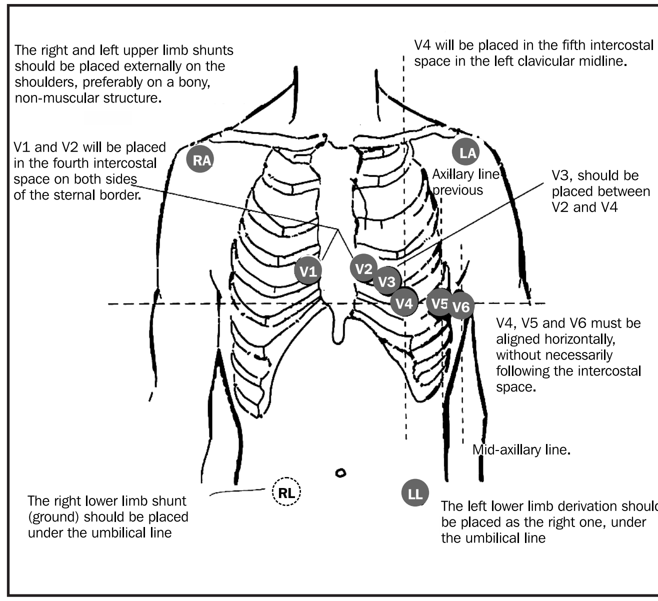
- Avoid intense physical activity or unusual exercise in the 12 hours prior to the test.
- Do not drink coffee, alcohol or other stimulants, or smoke, from 3 hours before the test.
- Do not eat during the 3 hours prior to the test. The usual medication can be maintained by ingesting it with a small amount of water.
- In tests of athletes with a history of cardiac pathology, when the objective of the test is to diagnose ischemia, habitual medication may be stopped because some drugs (especially beta-blockers) may decrease the effect of exercise on HR and the BP. In this case, if no signs of ischemia appear, the diagnostic value of the test for coronary heart disease is limited. The time required for medication stop is a minimum of 24 hours for sustained release drugs, instructing the patient to retake the medication in case of symptoms. Record the medication that the patient is taking when doing the test, in order to be able to correlate it with possible findings during the test.
- Provide detailed information about the procedure to be performed and its purpose, including probable symptoms that may arise, complications of the test and the criteria for detention. After receiving the appropriate information, the patient will accept the test by filling the informed consent.
- The objective of the test must be determined before its realization (in case of doubt, it is recommended to contact the doctor who prescribes it), in order to optimize its diagnostic value and guarantee the maximum safety of the athlete.
- The athlete should wear comfortable clothes and comfortable walking shoes or sneakers.
- It will be essential to carry out a brief anamnesis and a physical examination in order to detect important symptoms or signs, such as heart murmurs, cardiac galloping, pulmonary wheezing or rales, which may lead to suspicion of congenital or valvular cardiac disease, determining possible contraindications for the performance of the test.
- Measuring of the BP of the subject in vertical position should be performed before the test.

cables attached to a digital conversion box that transmits the records wirelessly[50].

Electrocardiographic leads for the stress test

Before starting the effort, an ECG should be obtained in decubitus and another in orthostatism. The six shunts corresponding to the horizontal plane (from V1 to V6) will not change between rest ECG and effort ECG. However, because during the stress it is not possible to place the electrodes on the limbs to obtain the frontal plane leads (DI, DII, DIII, aVL, aVR and aVF), these electrodes usually move to the torso, generally under the clavicles (for upper limb leads) and under the last rib (for lower limbs), as shown in Figure 5. If another electrode arrangement is used, it should be duly referenced in the report, given that the morphologies

Figure 5. Placement of the electrodes for the stress test



of the QRS complex and the T wave vary, although the resulting plot may be perfectly valid for interpreting rhythm disturbances and ST segment deviations.

Depending on the choice of ergometer to perform the ST, a variation in the arrangement of the electrodes of the frontal plane leads may be necessary to avoid artifacts in the electrocardiographic record due to excessive movement or position of the individual. For example, in the cycle ergometer, as well as in the row-ergometer and in the kayak-ergometer, due to the flexion of the trunk it might be convenient to move the electrodes from the shoulders to the back of the torso, being necessary its warning for a correct Interpretation of the layout.

Monitoring and clinical responses

Perception of effort

During ST it is usual to maintain some kind of control over the subject's subjective perception of effort. Although this habit is born in the field of clinical ST due to the need to control the occurrence of dyspnea in patients[2], it has been widely extended to SM to establish the level of fatigue during the test, and to sports training as a subjective measure of Intensity of training or competition.

In the field of sport, the most widely used tool for this purpose since the 1970s is the Borg scale[75,76]. The original scale (Borg RPE Scale) 2 uses a score of 6 to 20 and presents a supposed relationship with the effort HR, multiplying it by 10. That is, a scale of 15 would be equivalent to a HR of 150. Subsequently, a scale Reduced from 0 to 10 (Borg CR-10 Scale), which shows a good correlation with other scales such as Likert or the visual analogue scale[77-79], and that is even used for the subjective perception of AT[80].

The use of this reduced scale is usually indicated in the ST to assess the sensation of fatigue in specific areas (eg muscle pain, quadriceps fatigue or respiratory dyspnea), while the original scale of 6 to 20 has been shown to be Useful for the global assessment of fatigue[81].

In any case, the control of subjective perception during ST is much more useful when clinical assessments are being performed in patients with some pathology. Thus, it is known that in patients with heart failure the end of exercise due to dyspnea is associated with a higher incidence of cardiac events and with worse cardiorespiratory markers in ST than the end of fatigue[82].

Scales that assess chest pain in combination with other variables are also used in the ST for the assessment of ischemic heart disease. These include the Duke scale[83], which assesses chest pain in relation to ECG waveform morphology and effort tolerance.

Functional capacity

The functional capacity is given by the energy cost necessary to maintain an activity, and can be evaluated directly during an ST by measuring the VO_2, understanding that the maximum capacity of a subject would be given by the maximum value of this variable. The VO_2max is defined as the value of VO_2 that cannot be surpassed even though it continues to increase the workload, and is characterized in the ST by the appearance of a plateau in the final phase of the exercise when the VO_2 is represented by the workload[3]. Any exercise intensity can be expressed as a percentage of VO_2max, thus designating the VO_2 required for that activity as the percentage of maximal consumption.

Knowing VO_2 and VCO_2, a very exact caloric calculation can be made from the respiratory quotient (RQ), since for each value of RQ between 0.7 and 1 there is an equivalent of expenditure in kilocalories (kcal) per liter of Oxygen consumed. This technique is known as indirect calorimetry and is considered the reference method for measuring energy expenditure under controlled conditions[84,85]. However, it is possible to do approximate conversions considering an average caloric equivalent of 5 kcal for each liter of oxygen consumed[86].

On the other hand, it is quite common in ST to assess functional capacity in MET. A MET is defined as the amount of oxygen consumed by a subject at rest, in a sitting position, and is equivalent to 3.5 milliliters of oxygen per minute and per kilo of body weight (ml/kg /min) [5], or 1 kcal Per hour for each kilogram of body weight (kcal/kg/h). This concept represents a way of expressing energy cost as a multiple of the resting metabolic expenditure that is simple, practical and easy to understand. Its use focuses on the energy assessment of different physical activities from tables[87], and in the case of ST is limited to those tests in which no gas measurement is performed and, therefore, VO_2 data are not available.

Apart from metabolic and energetic assessment, the analysis of the VE and its relation to CO_2 elimination is also an indicator of functional capacity in some special situations, such as heart failure. The index most used to assess ventilatory efficiency is the slope of the VE increments versus those of VCO_2, known as VE / VCO_2 slope[3]. It has been discussed whether this slope should be measured in the whole test or only up to the second threshold (VT2), before the metabolic acidosis ventilatory compensation appears, and it appears that the measurement in the whole test provides more Information[88,89].

Regardless of the method used, a VE / VCO_2 slope of less than 30 is considered normal, irrespective of age and sex[90]. However, in certain pathologies, such as heart failure, pulmonary hypertension or chronic obstruction to airflow, this slope can be very high and reach values of 60 in severe cases[91-93].

Physical signs and symptoms

ST provides a series of clinical, electrocardiographic and metabolic variables that allow an objective estimation of the subject's degree of effort, determine the response of the cardiovascular system and its adaptation to exercise, and, on the other hand, detect some diseases in real time. The evaluation of perceived symptoms and signs is an integral component of the test.

In the course of ST, patients will experience certain sensations that may be of clinical importance. In addition, ECG, BP and HR must be monitored continuously, which gives information on the patient's clinical situation.

An ST must be permanently supervised by a specialist doctor who is familiar with its performance and is able to resolve any complications that may arise, ranging from simple locomotor injuries to MI, arrhythmias, hemodynamic instability and even death[5,94].

Therefore, when performing an ST it is important to follow up clinically assessing all the symptoms and physical signs that may appear.

The most important symptoms to consider during ST are:

- Chest discomfort or chest pain. Chest pain may be of ischemic origin (angina, coronary spasm) or other reasons. Typical angina, atypical angina, and non-anginal pain, which may be secondary to pleural, gastrointestinal, musculoskeletal, or psychogenic cause, should be differentiated. When anginal pain with no history appears, the test should be discontinued when ECG[95] changes are observed.
- Dizziness or fainting that may be accompanied by vegetative symptoms, such as nausea, pallor or gastric discomfort, and may be presyncope.
- Syncope: is a transient loss of conscience secondary to an overall reduction of cerebral blood flow characterized by having a rapid onset, short duration and complete recovery spontaneously. In an ST, the most common syncope is cardiovascular, which may be an indicator of severe arrhythmias or other heart disease, but also reflex syncope (eg after physical exercise) or secondary to orthostatic hypotension96. People who suffer from cardiac syncope have an increased risk of death; In the case of presenting in the course of an ST, the test will be interrupted and if it is of cardiological origin the hospitalization is indicated.
- Palpitations: an abnormality in the heartbeat that may appear during the exertion or during the recovery period. They are usua-

lly produced by arrhythmias or other structural heart diseases, although they may have another noncardiac cause.

- Respiratory distress (dyspnea): pulmonary hyperventilation (tachypnea) occurs during exercise, but dyspnoea can be evidenced along a ST and is a good indicator of functional capacity. It may be due to CVD (coronary ischemia, heart failure, valvular pathologies, arrhythmias ...), diseases of the respiratory system, allergies or infectious diseases, among other causes[82,97].
- Muscle fatigue disproportionate to exertion. It can be an expression of a disease (enzymatic, endocrine ...) that affects the muscles.
- Subjective perception of intensity of effort. The Borg scale is a reliable indicator of fatigue[2].
- General discomfort.

On the other hand, during the development of ST, it is necessary to control the physical signs that may have clinical repercussions and in some cases may be grounds for interruption of the test. It is important to monitor, observe and analyze the real-time behavior of HR, BP, ECG, and respiratory rate (RF) during the test.

Within the signs, it is necessary to observe the general appearance of the individual during ST. Signs of poor perfusion, such as cyanosis or pallor, cold sweating or nervous system disorders (ataxia, dizziness, vertigo ...), are very important and may serve as criteria for the suspension of the test[2,3]. Tachypnea is normal during ST.

HR is the best indicator of exercise intensity, so it is important to monitor your changes throughout the test at all times. The response of the cardiovascular system to exercise is to increase heart rate linearly with increased workload and O_2 consumption (around 10 bpm for each MET), although in well-trained subjects the increase is slower when the same protocol is used[3,98].

The relationship between exercise intensity and HR must be monitored, since it allows the analysis of exercise adaptation[3]. The HR response is caused by decreased vagal tone and increased sympathetic flow, but it is influenced by other factors such as age, physical condition, type of exercise, health status and some therapies. If 85% of the estimated HRmax is reached, the test is considered valid for myocardial ischemia[98].

When the HR is not increasing with the intensity of the exercise, the existence of coronary heart disease with alteration in the ventricular function must be suspected. There are publications that relate chronotropic incompetence with an increased risk of death[2], and is common in pathologies such as heart failure.

It is necessary to be attentive to an abnormal hyperresponsiveness of the HR to the exercise and to evaluate the existence of alterations of the peripheral resistance, ventricular dysfunction or arrhythmias, although it can also be secondary to anemia or to metabolic disorders[3].

HR should also be monitored during the recovery phase of ST, since poor recovery can be a worrying sign and can be used to assess health status. A fall of 17-20 bpm during the first minute of recovery is considered normal, and when it is lower, especially if it is ≤12 bpm, these people are at greater risk of death[99-101].

BP is another very important value that should be measured in the course of ST (at least every 2-3 min) and during recovery, and more frequently in high-risk patients. It depends on cardiac output and peripheral vascular resistance, although it is influenced by age (increasing with age), sex (slightly higher in men) and fitness (increasing physical fitness increases maximum SBP).

The normal response to exercise is a gradual increase in SBP as the intensity increases, until it stabilizes or falls slightly at maximum exertion. The DBP is maintained or decreased a little along the ST[2,102].

Increases in SBP in incremental ST are about 7-10 mmHg per MET, according to the majority of authors[3,103]. In the recovery phase, the BP figures normalize in about 6 minutes, although in some cases it may take up to hours.

There is no agreement on the normal maximum BP values that can be found in an ST, but the limit of normal SBP is around 220-230 mmHg and that of the DBP around 100-110 mmHg[104].

An abnormal response of BP, hypertensive or hypotensive may be found in the test. When an excessive hypertensive response to exercise occurs in healthy individuals with normal BP, there appears to be an increased risk of developing hypertension in the future[103,105].

When the SBP is greater than 250 mmHg or the DBP exceeds 115 mmHg, the interruption of the test will be considered.

An insufficient increase in SBP during ST (<20-30 mmHg) or a fall in ST in relation to resting values may be caused by left ventricular dysfunction, myocardial ischemia, or aortic obstruction, or because the patient is Taking some medications (beta-blockers). When the fall is> 10 mmHg below the rest values, the test should be suspended[3,106]. Exercise-induced hypotension is associated with poor prognosis, although it may also be due to antihypertensive treatment or to dehydration, among other causes.

In some cases, an abrupt fall in SBP may occur when the effort ends, with dizziness, pallor and cold perspiration, leading to loss of consciousness.

Auscultation immediately after exercise helps in the evaluation of cardiac function. Blows of different characteristics can be heard. A systolic ejection murmur with 1-3 / 6 intensity of the Levine scale and a duration of less than 3 minutes in the recovery period can be considered within normality, although the differential diagnosis with pathological murmurs is sometimes difficult. Post-exercise mitral regurgitation murmurs may suggest left ventricular dysfunction[1].

On the other hand, the diastolic murmur of mitral stenosis may increase during exercise due to increased venous return and decreased diastolic time, and in the case of aortic insufficiency the response of the murmur is more variable.

During ST, signs of circulatory failure and poor perfusion (dizziness, cyanosis, pallor) may also appear.

Finally, we must also take into account other annoyances that may accompany a ST:

- Electrodes placed on the chest to record heart activity may cause a mild burning or itching sensation.
- The sphygmomanometer that is placed on the arm to measure at certain intervals the BP, when inflated, causes a feeling of compression that can be annoying. Initial measurements of HR and BP will be taken before beginning the exercise.
- Adaptation to the ergometer (tape, bicycle ...) can also be uncomfortable.
- Tiredness or discomfort in the legs.

Post-exertion control

After an ST, as well as after any type of exercise, there is a recovery period until it reaches the pre-stress situation again, which has its own physiological characteristics and which must also be analyzed, among other reasons because there are some abnormal responses Which are only evident during recovery[107].

It is recommended to monitor a period of 6 to 8 minutes[3], of which the first 2-3 minutes should be walking at low speed. Of course, this period will be as long as necessary whenever the subject presents symptoms, we suspect some abnormal response or one of the variables has not returned to the previous values.

The HR presents a rapid deceleration in the first 30 seconds of recovery, linked to the reactivation of the parasympathetic tone, followed by a slower phase until reaching the previous values[108,109]. Anomalies in the recovery of HR have been shown to have an important prognostic value[17,110,111] and even since the work of Cole *et al.*[112], it is known that they can be a predictor of mortality in certain pathologies[99,113-117].

SBP usually drops rapidly due to falling cardiac output, and reaches its previous values around 6 minutes of recovery. Sometimes, the values are lower than the rest values and can be maintained for several hours[118]. However, if the exercise stops abruptly, some people have higher SBP values due to a decrease in venous return (due to backflow in the lower limbs), which causes a reduction in cardiac output with a consequent increase in vascular resistance in the systemic circulation[3].

On the other hand, the kinetics of VO_2 during the recovery also shows a fast phase followed by a slower phase, and has proved to be a very interesting variable to study[119] because, on the one hand, it correlates with the replenishment of the energy deposits that are Have used during exercise[201], and on the other, it is an indicator that recovery is itself an active process in which oxygen is consumed. This amount of energy consumed (which is excessive for the resting state and formerly referred to as "oxygen deficit") is known as excess post-exercise oxygen consumption (EPOC)[121,122] and is used to restore Functions that have been altered by exercise (increased ventilation and body temperature, excess lactic acid, etc.). In general, the EPOC measurement in healthy people is proportional to the volume of exercise performed, but in certain situations (anemia, hypoxia, peripheral arterial disease or some myopathies) will appear elevated3. In some cardiopathies, elevation of EPOC is indicative of exercise intolerance and has an important prognostic value[123].

The effort electrocardiogram

Normal electrocardiographic findings in the stress test

The effort causes some electrocardiographic modifications, which are described below[3,124].

P wave

During exercise, the amplitude of the P wave increases significantly in the lower face leads. The duration of the P wave generally does not change or increase minimally.

PR Segment

During the exercise, the segment PR is shortened and the slope of the path descends in the derivations of the lower face. This phenomenon has been attributed to atrial repolarization and may cause apparent ST-segment depression when atrial repolarization persists before premature ventricular repolarization.

QRS Complex

The duration of the QRS complex decreases as exercise increases. The Q wave, measured in the lateral leads, tends to increase its magnitude during exercise in normal subjects, while the R wave decreases and the S wave tends to increase in the lower leads.

Point J and upward trend of ST segment "upsloping ST"

The J point, which represents the end of the QRS complex and the beginning of the ST segment, can be reduced in the maximum exercise, and then return to the pre-exercise values in the recovery. The upward trend of the ST segment (upsloping ST) at peak exercise may be found in up to 20% of normal subjects, and J point depression is more common in older individuals. The magnitude of ST depression should be measured 80 ms after point J to assess myocardial ischemia (Figure 6). In normal subjects, with an elevated J-point due to early repolarization disorders, the ST-segment level usually normalizes with exercise. This is a normal observation and should not be considered as an ST depression in relation with the base line of the elevated J point.

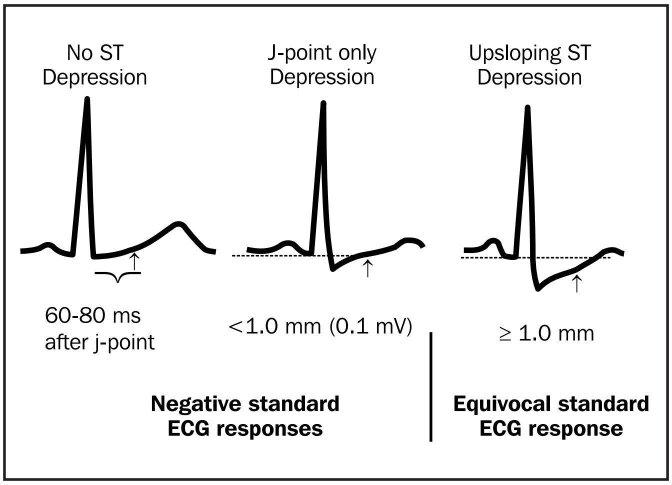
Wave t

During the initial stages an overall decrease in T-wave amplitude is observed, but reaches normal values during maximal exercise, and even higher during recovery initiation. In individuals with negative T waves in basal ECG prior to exertion, T-wave positivization with exercise is somewhat common and does not indicate absence of myocardial pathology.

U wave

There are no significant differences during exercise. It should be noted that with HR greater than 120 bpm the U wave becomes very

Figure 6. Point J. Normal variations of the appreciation point at J 80 ms with ascending ST segment[3].



difficult to identify, due to the approximation of the T and P waves that occurs with tachycardia.

QT. Dynamic range

As a result of the relationship between interval and duration, the action potentials are shorter as HR increases with exercise, and therefore results in a QT interval affected by neurohumoral changes accompanying exertion. In most normal subjects, QT decreases by exertion, although in some subjects, mainly women, there may be a paradoxical QT prolongation in the first minutes of the test. It is normal for measurements of the corrected QT interval, using the Bazett formula (QTc = measured root QT / RR), to increase at the onset of exercise and subsequently decrease as it increases. Some studies value as a prognostic factor the difference between basal QTc and QTc at 4 min of recovery[125].

Abnormal electrocardiographic findings in the stress test

Alterations of the electrocardiographic record during and after ST are often predictive and, occasionally, pathological. However, it is necessary to know that the ST is not a limiting test. ST, in the best hands, has an average sensitivity of 68% (40-70%) and a specificity of 77% (60-80%)[3]. In addition, subjects who, before ST, have a low risk of disease are more likely to have a false positive if the test is positive (corresponding to younger, trained and with few people Risk factors, as in sports cardiology). On the contrary, in high-risk groups a priori, a negative test may be a false negative.

Heart rate abnormalities

HR can show rapid tachycardia (inappropriate tachycardia) with exercise, which has clinical significance only in the case of preexisting heart disease (poor ventricular contractility from any cause or flow obstruction that produces low expenditure, such as valvulopathy Aortic disease). If there is no heart disease, it is worth noting the existence of groups of people, more frequently women and young people, who constitutionally present higher basal and exertional HR than usual, without this being a pathology.

Conversely, there is an inability to raise HR with exercise (beyond the more moderate elevation of well-trained hearts). This "chronotropic disability" usually responds to pathology of the specific cardiac conduction system. Both chronotropic incapacity and inappropriate tachycardia are usually clinically expressed by fatigue, dyspnea and eventually tendency to presyncope.

ST should aim to achieve submaximal HR, not only for functional assessment, but also to confirm the absence of pathological data in the most aerobic segment of ST. The inability to achieve it, and especially the lower HR is reached (due to the appearance of symptoms, signs or electrocardiographic alterations), implies an increased risk. In this way, not reaching the 2 MET is an ominous indicator[126]. It is considered as expected to exceed 6 MET (first stage of the Bruce protocol).

QRS morphology abnormalities

The voltages of the QRS complex usually have a tendency to decrease with exercise. The increase in voltage is usually considered indicative of an abnormal response, but there is no quantitative or qualitative marker of specific pathology associated with this finding.

In Wolff-Parkinson-White syndrome (WPW), the presence of a delta wave that does not decrease in magnitude and duration with exercise, but is maintained or increased, is not normal and is related to anomalous beams of short refractory period or with deterioration of conduction by the conventional route[127]. These circumstances are most frequently associated with pre-excitation mediated tachycardias.

The occurrence of a branch block with exercise, especially if it is of the left branch or branches (with extreme deviation of the frontal to left or right axis), is usually associated with ST positivity for ischemia[128]. Right bundle branch block (RBBB) rarely occurs during exercise, but would have the same connotations as the previous case.

The appearance of Brugada channelopathy signs (R 'slow wave with prolonged ST elevation and inversion of T) with exercise may be a marker of the syndrome, but does not presuppose its severity or risk, although it does require an electrophysiological study.

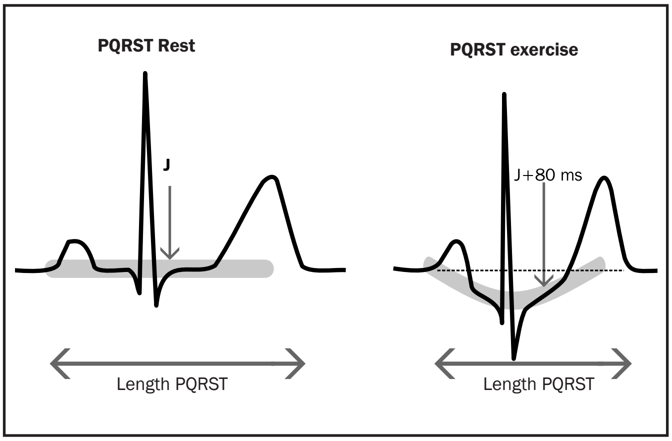
Repolarization abnormalities

The assessment of repolarization anomalies requires understanding the dynamics with which the ECG morphology is modified during exercise (Figure 7).

The resting ECG has, from the beginning of the P wave to the end of the T, an isoelectric line (base line) that is straight and horizontal; it's like a "tight rope" from the beginning of P to the base of the peak of T, on which all the waves rest.

With exercise, the space between P and T is reduced by tachycardia and as a consequence, that "cord" has less distance between the points

Figure 7. Morphological changes in PQRST with the effort.



of tension and loosens. The rope anchored QRST tends to follow the new form of "hanging string", with the nadir (lowest point) at the end of the QRS, near the point J. This visual image helps to understand the normal ECG of the effort, and value the subsequent anomalies that will arise with pathological situations.

Repolarization usually shows most of the findings related to the positivity of an ST, and they usually do it for two problems: coronary disease and hypertrophy (appropriate, inappropriate and atypical). Both situations usually drag the ST space down, depressing it. However, more data is needed to be detailed in order to make these changes specific. In addition, there are T wave modifications associated with ST changes.

In the case of exercise-induced ischemia (coronary disease), a ST decrease greater than 1 mm (0.1 mV) will be observed. The ST measurement should be done 80 ms from the start of the J point. The ST slope will also be assessed as flat or negative (downward), and if the T wave has become symmetric or inverted.

The ST descent pattern greater than 1 mm at J + 80 ms with negative slope and symmetrical T is accentuated as more exercise is done and more ischemia is induced. In addition, it never appears universally in all leads, but only in regions that are topographically coherent with the area undergoing ischemia. The derivations of the lower (DII, aVF and DIII), high lateral (DI and aVL), low lateral (V5-6) and anterior (V3-4) sides express well with exercise. The septal region (V1-2) does it poorly and with less reliability, and may also show alterations of the posterior mirror face (elevation instead of ST decrease) (Figure 8).

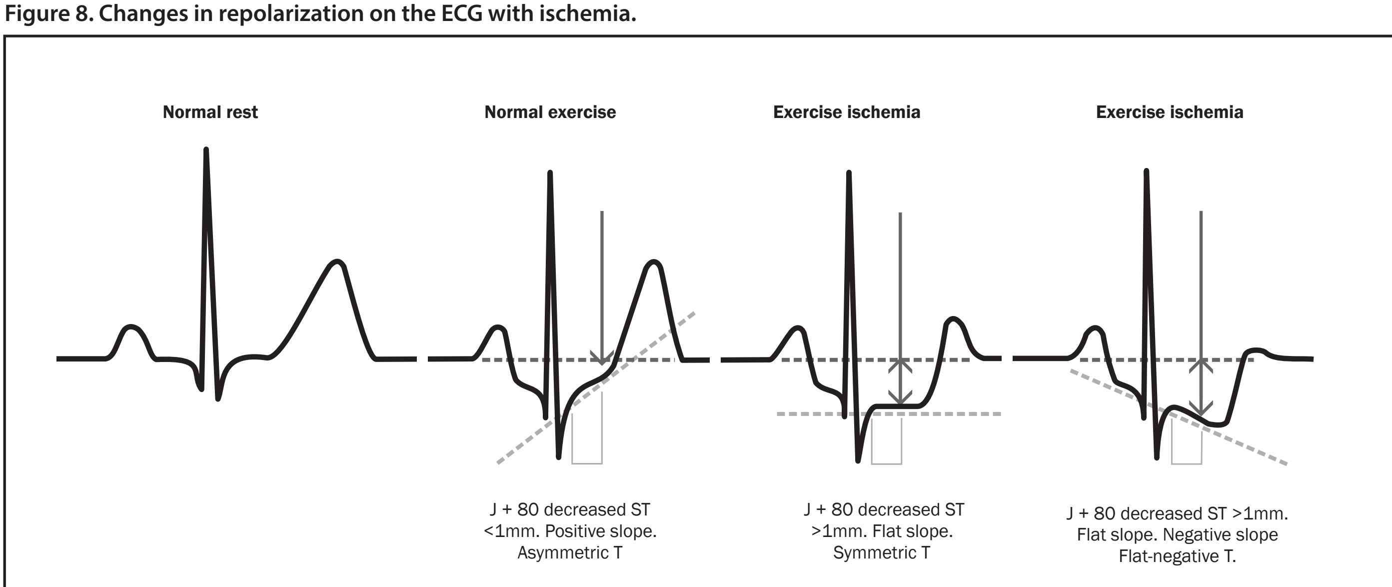
In the case of hypertrophy that increases ventricular overload with exercise, there is a decrease or increase of the ST decrease, maintaining the negative slope, although the T remains asymmetric in any case. In appropriate hypertrophy of the heart motivated by training, ST-T alterations tend to normalize with exercise.

In the pathological alterations of repolarization of atypical hypertrophy, ST-T alterations remain or tend to increase with ST loading. If the hypertrophy data on the resting ECG are not marked, there may be difficulties in distinguishing the repolarization abnormalities that occur with the exercise, distinguishing them from the purely ischemic ones. In this case it is necessary to resort to other data from the ST, such as the presence of anginal pain with exercise or the appearance of a malignant arrhythmia, to assess the meaning of repolarization alterations.

In case of doubt, it is best to label the test as "ischemic" and proceed to a larger cardiologic study to determine if ST was truly ischemic or was a false positive for ischemia.

Isolated changes in the T wave have limited diagnostic value.

Figure 8. Changes in repolarization on the ECG with ischemia.



In some cases, ST can be elevated with exercise and eventually associated with an inverted symmetric T. This finding may have two causes: a dyskinetic region or a myocardial wall aneurysm (where ST elevation occurs), or the exercise has triggered a coronary vasospasm that manifests with elevation, rather than a decrease, of ST. It is unlikely that "during" ST an MI is developed, but it can happen sometime later.

At the end of the ST, in the recovery period, alterations of the repolarization of often ischemic meaning can occur, not only because recovery phenomena are slower than the activation ones, but because after physical activity stops HR falls faster than the BP normalices, so there is a period after exercise in which the HR × BP product is not sufficient to support the demands of myocardial O_2 (and of all organism). During this period altered phenomena in repolarization can be increased (or prolonged) as described above.

Arrhythmias and blockages

Arrhytmias with a pathologically meaning during ST are mainly those produced by exercise itself. The most frequent ones are ventricular extrasystoles, which have a clear pathological significance if they increase their frequency as the exercise load increases, or if they increase their complexity, manifesting themselves with different morphologies (polytopia), in clustered forms (doublets, triplets) Or in ventricular tachycardia (torsion spasms, non-sustained ventricular tachycardia, catecholaminic tachycardia).

The appearance of a flutter or a VF is an ominous sign that forces immediate action; probably due to ischemia or cardiomyopathy.

Supraventricular arrhythmias are not usually significant, but exercise rarely causes atrial fibrillation (AF), which is self-limiting or sustained over time, even after stopping exercise. AF is not a benign event, and its possible causes are very varied: ischemia, mitral or aortic valvulopathy, pulmonary hypertension and pulmonary diseases, or disease of the specific conduction system.

An exercise-induced supraventricular tachycardia is also not a benign event. The most likely causes are the presence of a WPW (hidden or patent on the resting ECG) or an abnormal nodal beam. It does not give up spontaneously during the exercise and continues after finishing it.

The occurrence of a first-degree atrioventricular block (AVB) is exceptional; On the contrary, the PR space tends to shorten slightly in the ST. The appearance of a second-degree AVB, including the Wenckebach-type block although having a more functional character or third-degree nature, not only forces the ST to be stopped, but must lead to a deeper study to discover its origin, which may be an aortic valve disease, coronary disease, or cardiomyopathy. During the recovery of ST, in the vagotonic period, AVB may also appear, including a slight elongation of the PR that can be considered functional, but the clinical significance of the highest grade blocks is obscure.

Altered basal electrocardiogram (pre-stress test)

It is possible that basal ECG at rest may affect the interpretation of ST. There are a number of abnormalities that should lead to suspicion of the electrocardiographic results of ST, or even that may force varying ECG interpretation criteria. Even some findings may imply that it is not possible to perform ST with ECG because of the difficulty of interpreting it.

Branch locks

The presence of a BRD influences the interpretation of the ECG only in the leads in which there are alterations of the slow conduction, in particular the alterations that occur in V1-2, which will be more influenced by the BRD than by the presumed ischemia. This is not the case in the BRD with slow waves in ID and a VL, since if there is ischemia with the exercise it will cause a decrease in ST with a slow negative wave.

In the case of left bundle branch block (LBBB), changes in both QRS and even repolarization impede the interpretation of the results of the exercise. In this case, the ECG of ST is usually uninterpretable. In the previous hemiblock, the slower negative waves on the lower and lateral sides do not prevent the presence of ischemic ECG changes in ST. In posterior hemiblock (apart from the bleak prognosis in the context of coronary disease), positive waves on the lower face may alter the interpretation of ischemic alterations during ST at that location.

Atrioventricular block

The first degree AVB is neither contraindication nor impedes the interpretation of the ST. Higher grade blocks (second and third) may interfere with the course of HR changes.

Wolff-Parkinson-White Syndrome

The QRS morphology with delta wave included, with variations in magnitude with exercise, has little influence on ECG interpretation, but alterations in WPW repolarization (usually ST-T changes in the opposite direction to positivity or Negativity of the delta) can alter the consideration of repolarization during ST.

Atrial fibrillation

AF may have good control of resting HR, but unless it's treated it is very likely to have an inappropriate response to HR during exercise. In general it causes an increased tachycardia of the appropriate one, except if there is disease of the specific system of conduction in old persons, in whom tachycardia does not occur.

The presence of wide waves of AF, which is called fibriloflutter, alters the image of repolarization, making the interpretation of ischemic changes more dubious.

Ventricular hypertrophy

The presence of left ventricular growth does not alter the morphology of alterations of repolarization during exercise, but it should be considered that the variations of ST-T may respond more to an overload than to ischemia, thus the overall interpretation of the ST should be more careful.

Ischemic electrocardiographic signs

That the basal ECG already has signs of ischemia (low-grade or high-level ST, or T-wave alterations) requires careful interpretation of changes during ST. Basal variations should be considered as the starting point for those added during exercise. For example, a decrease in basal ST will require an additional decrease to be considered as an ischemic stress test.

Therefore, alterations in basal ECG should be taken into account when interpreting ST results.

Ergo-Spirometry

Ergo-spirometry, or analysis of expired gases during physical work, offers the opportunity to simultaneously study cellular, cardiovascular and respiratory responses under controlled metabolic stress conditions[129].

The performance of an ergospirometry requires a high preparation and an extensive knowledge of the parameters to be obtained, in addition to a correct calibration of the devices used.

The fundamental uses of ergospirometry in SM are the measurement of O_2max, the estimation of ventilatory thresholds, the assessment of the workload and the study of different metabolic parameters.

Parameters to be assessed and their interpretation

Oxygen consumption

It is perhaps the most important parameter to be evaluated by ergospirometry. Measured from the analysis of exhaled gas, as explained in other texts, 130 its importance is that it reflects the use of oxygen by the muscle cells involved in performing the exercise.

It should be remembered that the energy required for muscular activity is obtained in the mitochondria mainly from the oxidation of metabolic intermediates from the catabolism of carbohydrates and fats. The different mitochondrial catabolic reactions produce CO_2 and a flow of protons and their corresponding electrons, with oxygen being the final acceptor to form water[129].

VO_2 is expressed in absolute value ($l \cdot min^{-1}$ or $ml \cdot min^{-1}$) or relative to body weight ($ml \cdot kg^{-1} \cdot min^{1}$). Its value is a function of the workload being performed by the subject at that time, and as long as that load is stable, the VO_2 will remain stable within margins. In these conditions of stability it will reflect the energy expenditure that represents for that individual the accomplishment of a certain workload, and therefore its efficiency in the accomplishment of that exercise[131]. Therefore, depending on the exercise load, the higher the load, the higher the VO_2 reached.

This relationship between exercise load and VO_2, in the same individual, is not kept constant, but, based on a certain level of load, different for each person and according to their physical condition, a limit of capacity of oxygen utilization of ambient air. This individual limit, which depends on the maximum cardiac output, of the arterial oxygen content, of the fractional distribution of cardiac output to the muscles in exercise, and the muscle's ability to draw oxygen from the blood that reaches it, is the VO_2max[1].

The VO_2max concept suggests that although an individual performs an exercise load of greater intensity than the load at which his VO_2max has reached, he will not be able to increase VO_2. The ability to perform an exercise load of such magnitude will depend on the individual tolerance to fatigue, and therefore on the physical condition of the subject and their involvement in the performance of the test. In non-athletes it is very difficult to observe, and not in all tests with athletes it is possible to reach this situation of plateau. Under these conditions, it is preferable to speak more of VO_2 peak than of VO_2max[2].

Individual VO_2max can be reached by different ergometric procedures, or ST, either constant load or incremental load. Traditionally, incremental or progressive tests are preferred, because relatively low loads can be initiated for the subject, without the sudden application of too much force on their part. In this type of test, the VO_2max can be reached in 8-12 minutes, and thus the athlete will not be subjected to a high work load more than for a few minutes[129,132-134]. If the test were too short, the athlete would not be able to induce the vasodilation and sympathetic stimulation necessary to achieve sufficient muscular irrigation, and if the test was very long it could not reach the VO_2max due to accumulated fatigue.

It can also be tried to measure the VO_2max by means of protocols of realization of the maximum work load in a determined time, equal to which the VO_2max can be maintained. The most important weakness of this type of protocol is that not all subjects are able to maintain this degree of intensity during a same time[61].

Thanks to this direct relationship between VO_2 and charge, many times and in many environments it is a question of measuring "indirectly" the VO_2 from the exercise load realized. For a single person, this axiom is very close to reality, but shows many weaknesses when attempting to perform with different individuals.

When estimating VO_2 from the workload, it should be taken into account whether the estimation is performed on a steady-state work or not, the better or worse ergometer calibration if one is used, and the presence of obesity or any disease which may affect the transport of oxygen, such as heart, lung or metabolic diseases[129].

At the maximum load level, a further complication is added: given the loss of linearity between the load and VO_2 from VO_2max, when VO_2max is estimated from the load reached, its actual value is often overestimated.

The determination of VO_2max continues to be one of the most important and controversial points of ergospirometry, with authors who consider that with the type of tests commented and accepted by the great majority of the researchers, the real VO_2max is never reached[135-137].

In spite of these methodological difficulties, the clinical utility of the measurement of VO_2max is that it is the most widely accepted index in the world for assessing physical condition, and scales have been established for evaluation both in the general population[138,139] and in Sportsmen[133]. With these scales it is possible to compare the individual under study with a group of subjects with similar characteristics and to establish whether their VO_2max measured in a ST is adequate or not to their daily exercise needs or is appropriate for their level of competition[126] in case of athletes.

Ventilatory thresholds

Different activities and many sports specialties do not always imply a maximum power of energy in a necessarily short time, but rather a fraction of that maximum power for a long time. This is why it is also very important, for performance assessment, the determination of a parameter that provides this kind of information. This parameter is the AT, initially described by Wasserman and McIlroy[140], but whose definition can imply different concepts or biological processes according to the author consulted[141]. This is why, in the present text, it is preferred to use the term "ventilatory threshold", because it is the one that most appropriately conforms to the processes that are involved during the performance of an ergospirometric examination.

During an ST, it is observed a VE behavior (Figure 9) defined since 1980 as a three-phase model[142,143]. This model is based on the observation that during an incremental and progressive exercise the ventilatory response defines three different phases.

In the first phase, the stress load is low intensity for the subject being exercised, being fats the predominant energy source, appearing at the same time as a low stimulation of the glycolytic energy system. In this phase, VO_2 (Figure 9) and HR (Figure 10) gradually increase related to load, progressively decreasing the presence of O_2 in the expired air (F_EO_2) (Figure 11). On the other hand, VCO_2 increases (Figure 9) and thus also the CO_2 fraction in expired air (F_ECO_2) (Figure 11).

Figure 9. VE, VCO_2 and VO_2 during a stress test with progressive increase of the load every minute.

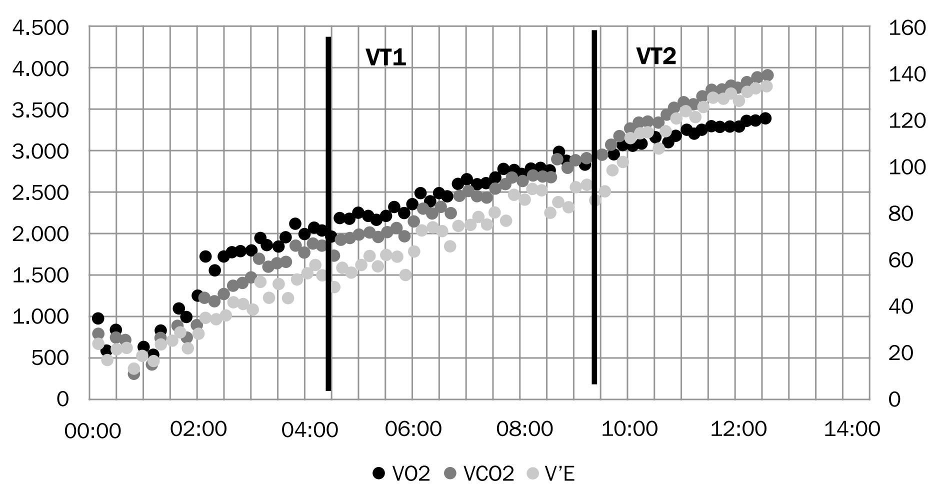


Figure 10. Heart rate (HR) and the VO_2/HR during a stress test with progressive increase of the load every minute.

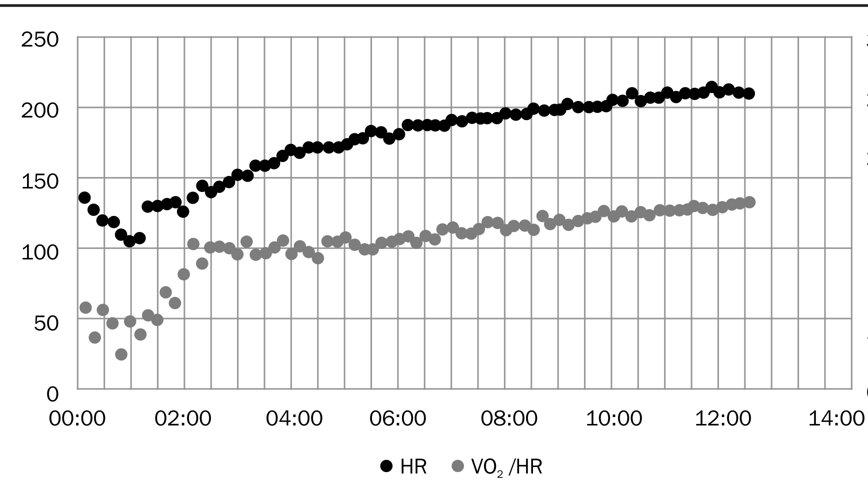
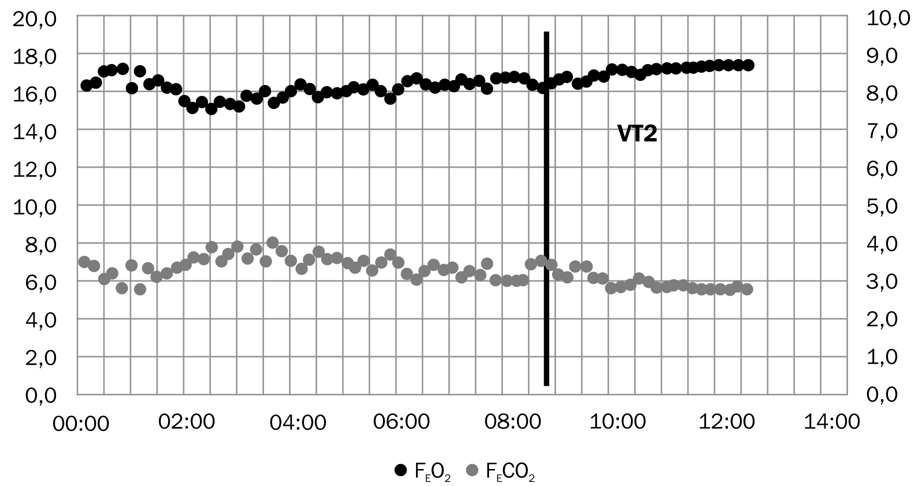


Figure 11. FEO_2 and F_ECO_2 during a stress test with progressive increase of the load every minute.



The situation will remain stable until, depending on the load and the indiviual's physical fitness, second phase starts.

During the second phase, VO_2 and HR keep increasing in linear relationship, while CO_2 production increases, in addition to the production of carbon dioxide by active tissues, because a progressive acidosis is established by the move of lactic acid to the blood, the greater the more the glycolytic energy system is stimulated. This metabolic acidosis is compensated by plasma bicarbonate, but induces a further increase of CO_2 in expiration. This will lead to an increase in F_ECO_2, but it will also produce bronchodilatation and an BF increase by neurologic way to maintain the partial CO_2 pressure of arterial blood ($PaCO_2$) within normal limits, limiting its progressive increase . Thus, the increase in VE is proportional to the increase in VCO_2 and not in VO_2 (Figure 10).

It should be noted that increases in VCO_2 and VE are greater than the increase in VO_2 due to workload, appearing a constant increase in RR and respiratory equivalent for oxygen (VE/VO_2) in this phase, while the respiratory equivalent for CO_2 (VE/VCO_2) remains practically constant (Figure 12).

Therefore, this phase is known as isocapnic buffer phase, because all the CO_2 produced is being buffered.

In this phase, VE increases proportionally to the VCO_2 increase (Figure 9), F_ECO_2 will remain practically constant, while F_EO_2 will increase progressively, due to a higher O_2 offer than needed for exercise load (Figure 11).

In summary, this second phase beginning is characterized by a proportional increase of VCO_2 and VE, higher than that of VO_2 caused by the exercise load (Figure 9), and this leads to an increase in F_EO_2 without a to the F_ECO_2 decrease (Figure 11)[142].

The change from the first to the second phase is known as VT1 or first ventilatory threshold, and corresponds to the AT described by Wasserman and McIlroy[140].

As exercise intensity increases, VO_2 and HR keep increasing until they lose that linearity, as has been previously observed, once intensity levels are close to individual VO_2max. In this third phase, metabolic acidosis is progressively greater and bicarbonate buffering is increasingly inefficient, which leads to a marked increase in VCO_2 and VE (Figure 9). The increase in VE is even greater than that of VCO_2, with a progressive increase in VE / VCO_2 and an even greater increase in VE / VO_2 (Figure 12). Even the increase in the VE is so great that the F_ECO_2 decreases, while the F_EO_2 continues increasing (Figure 13), because a smaller percentage of the total oxygen that arrives with inspired air is being used.

Change from the second to the third phase is known as VT2, or second ventilatory threshold, or even only as AT for some authors, which only increases the terminological conflict[144]. Since this increase in the VE is reflected in a progressive increase of the BF, while the Vt tends to remain more or less constant (Figure 12), there are authors who prefer to use this terminology to refer to stress hyperventilation or threshold of respiratory compensation[129]. Some authors want to match this moment with a certain value of lactatemia, but although they are close moments and it is clear that they are in part related[141,145], they are not necessarily coincident.

Heart rate

The response of HR is mediated by the general sympathetic response to exercise (Figure 10), and therefore its behavior will be partly

Figure 12. VE/VO_2 and VE/VCO_2 ratios during a stress test with progressive increase of the load every minute.

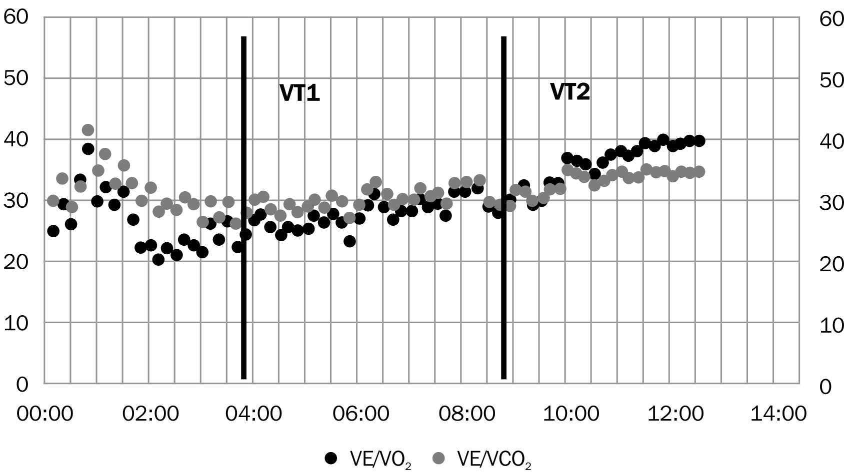
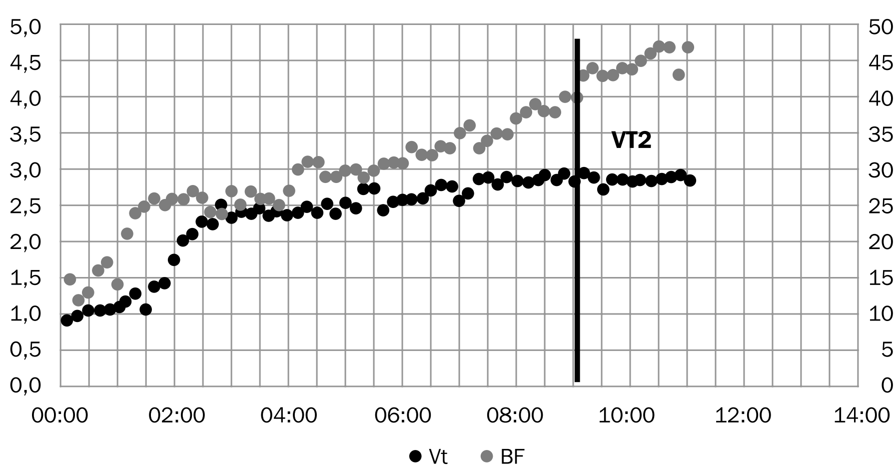


Figure 13. VT and breathing frequency (BF) during a stress test with progressive increase of the load every minute.



due to this stimulation and partly to peron's heart characteristics, its structure and its contractility.

The disproportionate response of HR at the beginning of the exercise is always striking, even though the load is not too high. In progressive tests this is not so obvious, but in maintained load tests for a few minutes it can be verified that, after a sudden initial increase, in the following minutes the HR decreases to the needed level for that load and that person (Figure 14), a well-known phenomenon for many years[146].

On the other hand, it is difficult to know in advance, before starting a ST, what HR a person will reach. Different approaches have been made, and even the most commonly used has never been published, but they are only relevant for populations, and have little interest to predict the HRmax that a person will reach when performing ST. In addition to health, it will depend on will, tolerance to high intensity workload, experience, personal training history, genetic factors and others, the only way to know it accurately is to perform a maximum ST[147].

Blood pressure

BP is a very interesting variable to consider during an ergospirometric test. However, its measurement is affected by the noise generated by the ergometers and the artifacts that can generate a extremities movement[129], which means that both the auscultation and the intra-arterial recording can be altered by factors external to the measurement.

The SBP (Figure 15) during an ergospirometric test tends to increase from rest values to close scores to 200-210 mmHg with maximal exercise. The increase in DBP is generally more moderate and usually does

Figure 14. Heart rate (HR) and VO_2/HR during a stress test with progressive increase of the load every 4 minutes.

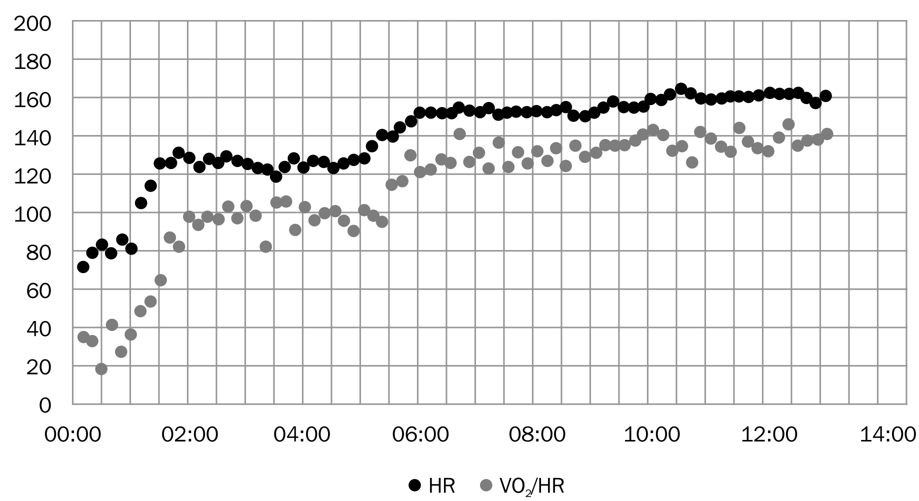
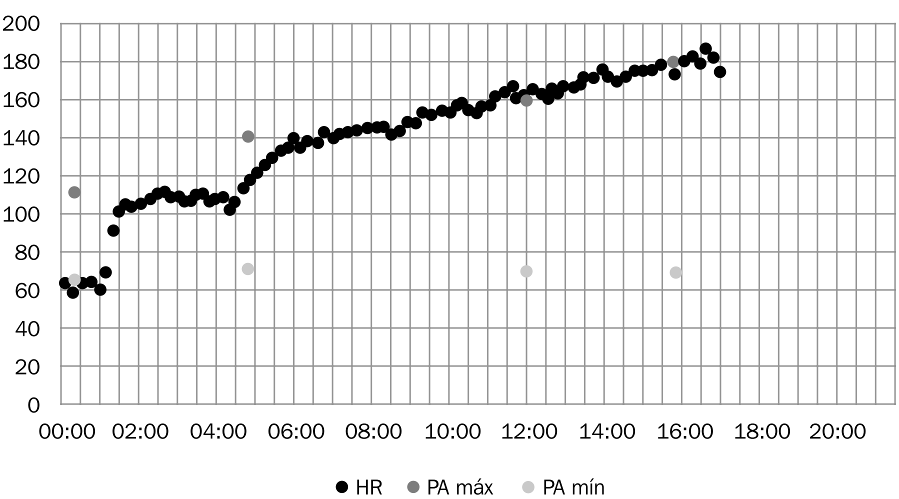


Figure 15. Heart rate (HR) and BP during a stress test with progressive increase of the load every 4 minutes.



not exceed the limit of 95 mmHg. There are no differences between sexes or age groups in this behavior, although higher values are usually presented in smokers[129].

Workload

In the ergospirometric tests, the workload is the way used to observe how the different study parameters are modified according to the selected work protocol. Depending on the ergometer used, there may be different forms of expression, but the standard reference unit is the power (W). Its choice is due to that it has a direct relationship with VO_2, since both measures are expressed as a function of time. The relationship is so adjusted that, for the indirect calculation of the VO_2 that an individual is doing while doing an activity, it is enough to know how many watts he is delivering in order to adjust it with a good approximation. Many approaches can be found in the literature[126,129,139].

Sometimes it is preferred to use another unit, the MET, to express the energy delivered. A MET is the energy requirement for basal metabolism, and is equivalent to a VO_2 of 3.5 ml / min per kilogram of body weight[126,148]. Therefore, expressing VO_2 in MET indicates how many times the baseline energy expenditure is being multiplied to meet the energy requirements demanded by the activity being carried out at the time of measurement.

When the working protocol is not incremental, but it is expressed as the performance of an activity of any intensity over a longer or shorter period of time, another way to indicate the workload performed is in joules (J, or its multiple kilojoules , KJ), which is a unit of work, or in calories (lime, or more frequently its multiple kilocalories, kcal, since the calorie is a very small unit), which are the equivalent of the joules as an energy unit (1 J = 0.239 cal). In short, they will be equal to the average power delivered during the whole development time of an activity multiplied by the time that has been performing that activity.

Lactate

Lactic acid is a tricarboxylic intermediate in the Embden-Meyerhof cycle[144], which is formed in the muscle cell from pyruvic acid and is discharged into circulation, much of it being recycled into other tissues.

The lactate that is measured in a blood sample is, therefore, the result of a process of synthesis and other processes of recycling (Figure 16). Its presence in the blood is in ionized form, since the lactic acid is a weak acid that gets divided in the pH of the blood.

Its measurement is simple, reliable and cheap, and can be done with capillary samples. It gets accumulated in blood depending on the workload, thus it allows monitoring the individual intensity that this workload represents for the subject under study. However, several precautions must be taken into account when using for training monitoring.

The accumulated lactate varies according to the workload and the presence of a greater or lesser sympathetic stimulus, so that in order to work properly it is important to reach a stable wrok state. Only then, the lactate measured will show the stress that the glycolysis is undergoing during the workload performed by that person. It is sometimes difficult to estimate how long it takes to reach a stable state, but if it is being monitored by an ergospirometry will always be easier, since it will be possible to observe how VO_2 gets stabilized while performing the load (Figure 16). It is generally accepted that a minimum of 3-4 minutes is enough.

Another precaution to be taken into account is that a for a workload performed lower than VT2, the blood sample for the lactate measurement must be obtained as soon as possible, during the same workload or just at the end of it. (The ergometer used will allow or not the measurement during work), since the lactate at these load levels usually drops very fast when the exercise is finished.

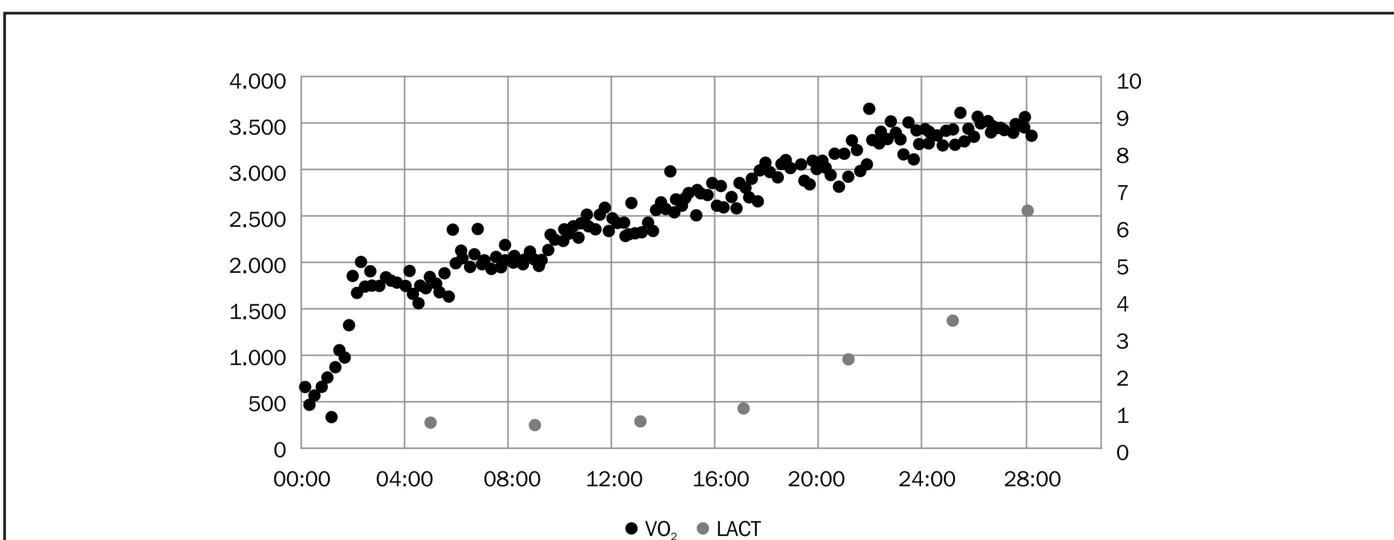
When the workload is higher than VT2, determining the blood lactate is more difficult, because a stable lactate state will not be reached, so its values will be changing depending on the duration of the workload. In these conditions it is often used as a tool that provides information on individual tolerance to such a workload. It is therefore appropriate to define the working protocol and keep in mind that only by replicating the conditions it will make sense to use this variable.

Many authors have tried to define different "thresholds" depending on how lacatatemia actuates with respect to workloads[144,149]. Although terminology has often been used even with the used in this work, described events by them are not the same, so they always have to be considered in their own context.

pH

pH measurement, which is the opposite of the logarithm in base 10 of the concentration of hydrogen ions in the blood, has been used many times but has lost value over time in favor of lactate measurement. On the one hand, its measurement is technically more complicated than that of lactate; On the other hand, the protons generated by lactic acid are by far the main ions that change in the blood during the performance of an exercise and, therefore, their control does not provide much more information than that provided by the lactate study.

Figure 16. VO_2 and blood lactate concentration during a stress test with progressive increase of the load every 4 minutes.



Ammonium

Banister *et al*.[150] observed that ammonium got accumulated at a much higher rate than lactate in function of the workload, and introduced its use in the assessment of exercise. The main source of ammonium in exercise is the deamination of adenosine monophosphate, and it increases linearly as the exercise load increases[150-152], so it was mainly used to evaluate very short duration and very high intensity exercise[152].

It has been verified that the increase of the ammonium concentration in the blood already occurs at low loads of exercise, being more remarkable the variation of the concentration in blood of ammonium that the one of lactate to any that level of load. This indicates that blood ammonia could be a better marker of fatigue control than lactate, especially when talking about very long-term work performed with low stimulation of the glycogen[151]. It may also be useful to assess the adaptation to exercise in situations of poor state of energy glycogen stores or in case of muscular diseases[144,153]. However, currently there are not many studies that control the effects of regular training on ammonium concentration in blood at different loading levels.

Interleukin 6

Interleukin 6 (IL-6) is a cytokine produced by muscle secondary to exercise, both concentric and eccentric[154]. Its behavior has been related to insulin resistance[155], management of carbohydrate deposits[155] and fat mobilization[155].

Its production and release depend on calcium homeostasis, glucose availability and the formation of free radicals[156]. The IL-6 formed this way acts both in the paracrine and endocrine forms and has systemic effects, such as the increase in the release of glucose by the liver and the increase of lipolysis[156]. During exercise, its synthesis and release into the bloodstream increase, thus facilitating the availability of substrates for active tissues[156].

It is also known that its synthesis increases the greater the load of exercise is, but above all the longer the duration of this. During a progressive loading exercise, it has been observed that IL-6 increases in parallel with increased load, adrenergic stimulation and the entry of glucose into the muscle[157]. On the other hand, its synthesis decreases when carbohydrates are administered during exercise. Therefore, the low availability of energy resources seems to be one of the main stimulus for its production[156].

Also, it has been shown that its blood concentration is modified by training[154]. Low physical fitness is associated with increased resting IL-6 values, while training tends to reduce IL-6 produced during exercise[156].

Although there is little experience for training monitoring, it seems to be a parameter whose use in the near future can be very interesting.

Blood gases

In ergospirometry in normal subjects, among them athletes, the blood gases are usually not very interesting because they do not present significant modifications when comparing them with other parameters. The arterial oxygen partial pressure (PaO_2) should not be altered during SS, and $PaCO_2$ tends to decrease with effort hyperventilation129. Blood gases are usually used in hospital services only, since in outpatient ergospirometries, approximate information can be obtained from the study of partial oxygen pressure at the end of expiration ($P_{ET}O_2$), arterial oxygen saturation (SaO_2) by pulse oximetry and carbon dioxide partial pressure at the end of expiration ($P_{ET}CO_2$).

If the SaO_2 is used, it should be taken into account that the pulse oximeters do not distinguish carboxyhemoglobin from oxyhemoglobin[129]. During exercise, mechanisms produced by movement, light interference, or pulse wave alterations may alter the measurement. However, it remains as an acceptable method for decision-making[129], when subjects under study present hypoxemias below 60 mmHg during the test; If not, pulse oximetry will not be enough to detect hypoxemia.

Outpatient ergospirometry is usually followed by monitoring of $P_{ET}O2$ and $P_{ET}CO_2$ (Figure 17), whose actions are not very different from those of the respective expired fractions (F_EO_2 and F_ECO_2), at least in normal subjects (Figure 9) .

Interpretation

Ergospirometry offers an unique opportunity to simultaneously assess the responses of the cellular, cardiovascular and respiratory systems in a situation of controlled stress[129], for which it is necessary to maintain constant the environmental conditions in which ST is performed according to the purpose of the diagnosis. If we want to see how the athlete gets adaptations to aworkload, it will be important that these conditions are as standardized as possible. If we want to check how the athlete gets adapted to the conditions in which a particular sport event will be developed, then it will be convenient that the conditions can be adjusted to those found during the development of the competition.

The interpretation of this type of exploration in athletes must take into account that they are subjects without any underlying pathology, or in case that there was one, this would have a minimal impact on the availability of energy.

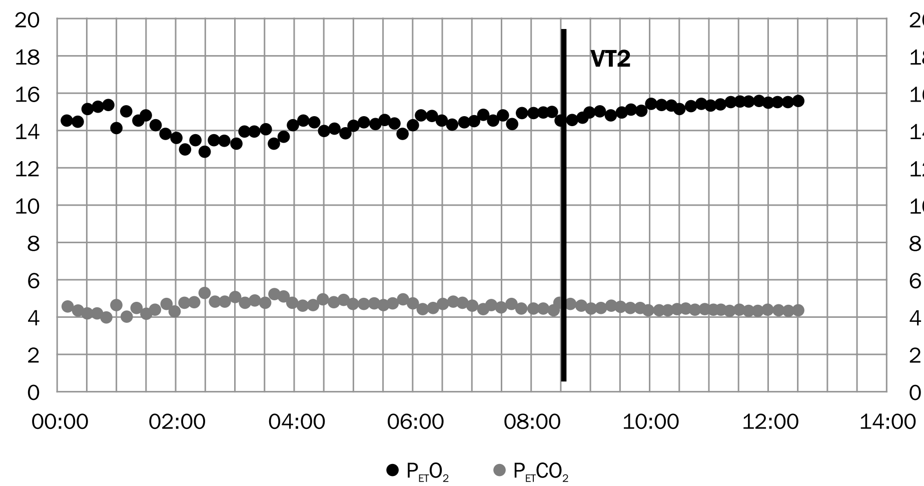
This type of exploration, in the first place, will be usefull to rule out the presence of base diseases that may occur during the exercise, or that could limit the adequate availability of energy resources for the athlete.

The main part of the interpretation should be aimed at assessing if the data obtained will be enough to have a good performance in the chosen sports specialty. At this point it will be very interesting to assess the VO_2max and the maximum load reached, as long as they can be related to the data obtained by other athletes of the same sports specialty[133].

However, it should not be forgotten that VO_2max is only a good predictor of performance among athletes who are very heterogeneous in their value. In athletes of the same specialty with similar VO_2max, other factors will be better predictors of performance[158].

Also the correct determination of AT will be important, because it will provide keys on the capacity of the athlete to work to certain

Figure 17. $P_{ET}O_2$ and $P_{ET}CO_2$ during a stress test with progressive increase of the load every minute.



fractions of his maximum efforts capacity. However, in this case also it should be assessed specifically for the sporting specialty being studied, due to that not all athletes will present the same type of adaptation.

Applications

The results obtained during an ergospirometry will be determined by the previously designed study protocol; Therefore, as the exercise load to be applied is known, the results obtained will respond to the applied stimulus.

The ergospirometric tests will serve, according to the protocol that is applied, to evaluate the power of the aerobic system of energy contribution of the athlete and his capacity of endurance, besides to obtain data that help in the prescription of the training or the prediction of the performance[141].

It should be taken into account that both growth and sexual maturation and the training process produce adaption changes in the individual's response to the training load, and therefore the response of a person to an ergospirometric test will depend greatly on his history of dedication to the sport and its preparation.

As previously observed in the case of VO_2max, this depends on different factors, some of them modifiable by training. Whenever exercise loads capable to induce in it are included in the training process, it will be interesting to assess secondary modifications to the training performed have been presented after that.

Respiratory threshold is similar. In fact, the determination of the ventilatory threshold is intended, in the case of athletes, precisely to the design and modification of the training plans[141,158], and depending on the different criteria that each follow for its application[149].

Diagnosis and prognosis of stress test

SS or ergometry (from the Greek ergon, work, and metron, measure) is a diagnostic procedure that evaluates the response of the heart to a progressive physical exercise. This test is one of the most widely used cardiac scans and provides important diagnostic and prognostic data in a wide variety of patients.

Certain individuals, such as those performing jobs which are relevant to public safety (pilots, air traffic controllers, bus or train drivers, etc.) and those performing jobs with large physical requirements (firefighters, etc.) should regularly perform a SS.

Prognostic value of exercise electrocardiogram

In addition to the role it plays in the diagnosis of coronary artery disease, stress ECG provides a standardized method to assess prognosis, regardless of whether coronary artery disease is present. Despite the importance of the use of ST for the diagnosis of coronary disease, new alternative diagnostic strategies are emerging, such as some imaging modalities (stress echography, stress MRI, etc.). The ECG request during the physical effort to assess the prognosis is increasing[159,160].

Very often, in addition, the exercise ECG has the utility of serving as a complementary point of view to aid in decision making[159,161].

Prognostic value of maximal exercise capacity

The ability to perform a physical exercise or the amount of work achieved before reaching exhaustion is a very powerful predictor when assessing survival. Many studies have specifically demonstrated the usefulness of the study of maximal exercise capacity to establish a prognosis[162-164].

"The longer and more intense the physical effort during an ST, the less frequency exist, for both men and women, of dying early, either because of a coronary artery disease, or because of other causes."

Many authors consider cardiopulmonary ST with gas analysis as a better way to evaluate the performance of physical exercise, because the gas analysis gives detailed information of the VO_2max, the ventilatory response and the level of physical effort reached[2].

The realization of functional capacity tests requires specialized equipment for this purpose, in contrast to what is necessary when performing the test with a treadmill or a cycloergometer. However, there is much literature demonstrating that exercise duration, with a standard protocol, is a predictor of prognosis in patients with both known and suspected CVD. There are some considerations that can help to optimize the value of standard ST in the assessment of maximum exercise capacity and its prognosis. For example, the widely used Bruce protocol was developed as a very efficient diagnostic test for middle-aged men, but it is not the optimal protocol for assessing maximal exercise capacity in a heterogeneous population, particularly in older adults, obese or untrained individuals. In these groups, with this protocol, it may occur that the test stops prematurely due to the constant increase in aerobic requirements, and it will be the physical limitation, instead of the physiological limitation, which will stop the ST. Thus, the prognostic implications, by a decrease in test performance, will decrease.

For these population groups, the recommended and most useful protocols are those that perform small increases in workloads, so that the energy needs to perform the physical exercise are light.

There is a limitation for the systematic evaluation of the prognosis about exercise capacity, and that when a ST is going to be performed for the purpose of carrying out a diagnosis by the image, many laboratories usually use as valid a ST that reaches the 85% of predicted maximum prediction, assuming that this point is sensitive enough to reach a diagnosis of coronary artery disease. This means that the purpose is not to perform physical exercise until exhaustion, with the consequences described to evaluate the prognosis. In addition, assuming that only 85% of HRmax results in a cardiac workload enough for the diagnosis of coronary ischemia is a point that has been questioned[165].

It is added to this weakness that, when assessing the exercise capacity, the test is often reported in terms only of duration, but the exercise intensity is not considered, so the value of the ST is decreased as a prognosis tool.

If physical exercise is quantified using METs, they provide a better format for reporting exercise capacity, and also facilitate a physiologically significant comparison of different protocols in which identical exercise times may have different prognostic implications.

Another limitation for quantifying exercise capacity as a prognostic marker is related to the challenge of comparing individual abilities with standards for similar age and sex[159,166,167].

Both diagnosis and prognostic evaluation could best be performed using ST protocols to the true maximum exercise capacity of each patient.

Abnormal chronotropic response to exercise

In section 2.3 (Cardiovascular response to exercise in normal subjects) the chronotropic response is explained as one of the cardiovascular responses to physical exercise.

Chronotropic incompetence is the inability to raise the necessary and accurate HR for a specific moment of physical activity performed or for the demand for that physical effort. A correct response of the HR will be accompanied by a correct elevation of the cardiac output, in order to cover the metabolic demands during the physical effort.

An altered and inadequate chronotropic response is a predictor of suffering some type of cardiac accident and of dying for any type of cause. Despite the theoretical value of this finding, the definition or concept of chronotropic response appears sometimes as ambiguous.

The easiest is to relate the HR achieved with the peak of the theoretical HRmax, which is known that decreases with age (220 - age), so that an inability to reach 85% or more of HRmax predicted by age is considered as chronotropic incompetence. However, basal functional capacity and resting HR are also related to the chronotropic response.

An alternative method for assessing chronotropic incompetence involves the assessment of the proportion of reserve HR used:

Heart rate reserve (HR Res): term used by Karvonen, is defined as the difference between the HRmax and the resting HR.

HR Reserve = HRmax – Rest HR

For example, a 40 years old person who has a resting HR of 70 bpm, his heart rate reserve would be

(HRmax 220 – age = 180)

180 – 70 = 110

If he reaches 157 bmp in the ST, calcutating the percentage of HR reserve would be

HR reserve (%) = (157 – 70) / (180 – 70) = 0,79 (79%)

87 / 110 = 79%

Lower values of 80% of HR reserve have been used to define a significant chronotropic incompetence[168].

Recently, in order to individualize chronotropic response in healthy adult individuals, new formulas have been proposed for the calculation and prediction of HRmax, which would be[169,170]:

208 – 0,7 × age (men)

206 – 0,88 × age (women)

Other conditions that may affect HR during exercise testing are a high level of training (especially endurance training) and treatment with beta-blockers, which may result in a decrease in HR increases for similar levels of submaximal work and also to a difficulty to reach the predicted HRmax. This is a highly observed and frequent cause in the sports assessment clinic, due in some cases to a high strength training performed with the lower limbs.

Finally, insufficient chronotropic response[171] (inability to reach 85% of predicted HRmax [MHRP]) or the presence of an inadequate chronotropic response are associated with an increased risk and a worse prognosis of ischemic heart disease in women[168,169,172,173].

Prognostic value of heart rate abnormality during recovery from physical exercise

Although a globally accepted criteria is that a decrease in HR, or a reduction from the peak of maximal physical exercise, equal to or less than 12 bpm after finishing exercise, and while the patient remains in standing position, is commonly used to define an abnormal HR response during recovery, this parameter has not been well established yet in terms of its importance[111].

Numerous investigations have shown that the decrease in HR during the recovery of a physical exercise is an important marker of suffering a cardiovascular problem, both in the healthy population and ill patients, and regardless of the differences in the patient population, the medication or base functional capacity[110,114,174].

The HR recovery depends largely on the exercise protocol used, but some inconsistencies found in the literature have led to some uncertainty about this index. The information obtained at the beginning of the HR decrease value during recovery was based on patients who, after finishing the exercise, remained erect and walked slowly for 2 minutes. With this protocol, a reduction of 12 lpm or less was identified as the best marker that increases the risk of death in these patients by four times. It has been seen, in contrast to the above, that some protocols are carried out in different positions of the patient at the end of the exercise, and according to the different protocols used the point of the recovery of HR tends to be greater. However, the implication in the reduction or deceleration of HR is similar in all of them.

Abnormalities of blood pressure during exercise and recovery

The definition of hypotension during physical exercise may present two different situations: the first is a decrease in BP below the initial pressure during exercise, and the second is when there is an initial increase at the beginning of the exercise followed by an equal decrease or greater than 10 mmHg[175], being this a potential situation to stop exercise, especially in the presence of ischemia or any other heart disease.

Pathophysiological mechanisms that induce hypotension during exercise include aortic obstruction and left ventricular outflow tract, left ventricular dysfunction and myocardial ischemia.

Exercise, which produces obvious hypotension, means a prognostic marker of increased risk of cardiovascular accidents[175]. In people without cardiac pathology, there may be other causes that cause hypotension, such as dehydration, problems with an antihypertensive treatment, or prolonged strenuous exercise.

An exaggerated BP response was defined as equal to or greater than 210 mmHg for men and 190 for women. An increase in DBP during exercise greater than 10 mmHg above rest values is considered abnormal and may predict an increased risk of coronary artery disease[176].

The recommended relative indications for stopping an ST are to reach numbers greater than 250 mmHg of SBP and 115 mmHg of DBP. An exaggerated increase in SBP as a response to exertion usually indicates an increased risk of hypertension in the future.

A failure of SBP to decrease or an increase in the recovery period, in a very short time, in relation to the values reached during the maximal exercise, has been shown to be a predictor of risk of death[177].

Arrhythmias during exercise and recovery

The importance or meaning of the presence of ventricular extrasystoles during exercise and recovery is yet to be established; although some studies indicate that their presence may mean an increased risk of death[178], others do not. However, some authors find an elevated risk of death in subjects presenting extrasystoles during recovery. On the other hand, a difference has been described with respect to the origin of extrasystole, which is that when the extrasystole has RBBB morphology it is associated with left ventricular dysfunction, and also with a higher risk of predicting a death, in comparison with extrasystoles originated in the right ventricular outflow tract[179].

Stress test in women and children

Stress test in women

The objectives and the usefulness of the realization of a ST in women are the same as in the rest of the population. However, women have been and still are underrepresented in research in many areas of cardiology and SM[180], and numerous guidelines and recommendations are often based on research conducted predominantly in men.

The following describes the general aspects to be taken into account in relation to the implementation of STs in women:

- The calculation of the indirect parameters from the data obtained in a ST and the interpretation of the results should be done with reference values or adequate equations to the female population.
- Women generally have a lower incidence of sports-related electrocardiographic alterations[181], but women's ECG presents some differential features that may influence the interpretation of the results obtained in a ST.

  Sudden sport-related death has a significantly lower incidence in women, even after taking into account possible differences in participation rates[182]. This information, in addition to emphasizing the importance of analyzing women separately from men in studies of heart disease, is of particular interest for the planning of the tests to be included in population screening.

However, the most important aspect to be taken into account in ST in women is the interpretation of the ECG (in particular ST-segment depression) and its implications for the diagnosis and prognosis of cardiovascular disease and coronary disease in particular.

Although the risk of CVD has traditionally been considered to be lower in women[183], in recent years, there has been an increase in the prevalence of ischemic heart disease in middle-aged women (35-54 years)[180,184]. In addition, there is currently evidence of inadequate management in the diagnosis of ischemic heart disease in women, a fact that is probably the cause, in part, of this increase in mortality and CVD morbidity in females[185].

Traditionally, ST segment depression, as a significant parameter of ischemia, has been found to be of less diagnostic value in women than in men[186,187]. There are numerous studies that show that the sensitivity and specificity of the diagnostic criteria for ischemic heart disease are slightly lower, although similar in magnitude, in women than in men (61% vs 68% and 70% vs 77% Respectively)[186,188]. In a meta-analysis of the United States Agency for Healthcare Research and Quality, which included 29 studies involving 3,392 women, a sensitivity and specificity was obtained for the detection of 62% of obstructive coronary disease (95% confidence interval (95% CI: 55-68) and 68% (CI 95%: 63-73)[189,] respectively, similar to those of a mixed population of men and women. In any case, it is likely that these differences are due, at least in part, to the higher frequency of basal changes in the ST-T segment, to the decrease in the electrocardiographic amplitude of the female sex[3] or to hormonal factors in relation to the concentrations of endogenous estrogens in premenopausal women or in postmenopausal hormone replacement therapy[190-193].

On the other hand, although the positive predictive value of ST segment depression in women in ST is significantly lower than in men (47% vs 77%, $p < 0.05$), the negative predictive value in symptomatic women is similar to that of men (78% vs. 81%)[190]. Thus, a negative exercise ECG in the setting of maximal exercise is useful to exclude obstructive coronary disease.

In addition, ST provides diagnostic and prognostic information, well beyond the ST segment response. Therefore, the AHA consensus on non-invasive tests for the diagnosis of ischemic heart disease in women185 proposes as parameters to take into account functional capacity, chronotropic response and recovery of HR, as well as the use of multifactorial risk index, among others.

Functional capacity

The level of functional capacity assessed with ST is one of the most important cardiovascular risk markers to be taken into account and is considered an independent predictor of coronary heart disease in women[194-200]. If in doubt, having a good physical capacity improves the diagnostic sensitivity and specificity of ST when associated with a decrease in ST[194,195].

From a series of 5,721 asymptomatic women, Gulati and Black[197] defined the maximum theoretical functional capacity in MET as 14.7 - (0.13 × age). Failure to achieve 85% of maximal theoretical exercise capacity was associated with an increased risk of all-cause mortality and cardiac-cause mortality in both symptomatic and asymptomatic women[197]. On the other hand, the achievement of a functional capacity of more than 10 MET, in men as well as in women, is associated with a lower prevalence of ischemia assessed by single photon emission computed tomography (SPECT)[201], and for every 1 MET increase in exercise capacity there is a 17-25% reduction in all-cause mortality[198,200].

In conclusion, for both prognostic and diagnostic purposes, the information related to the level of cardiorespiratory aptitude should be incorporated into the interpretation of the ST, although it is very important to adapt the protocol to the physical capacity of the women. The Bruce protocol requires initial workloads of 4.7 MET and gradual increases of 2-3 MET per stage, which can precipitate early fatigue in women with low muscle mass or low physical capacity. Therefore, in these cases, adapted protocols should be applied with small increases or start at lower workloads.

Chronotropic Response

When there is no increase in HR adequate to the level of effort during a ST, the existence of an insufficient chronotropic response is considered[171]. The inability to achieve 85% of the EMHR, or the presence of an inadequate chronotropic response, are associated with an increased risk and a worse prognosis of ischemic heart disease in women[168,169,172,173]. The formula proposed by Gulati and Shaw[169] for the calculation of EMHR in asymptomatic women is 206 - (0.88 × age). In any case, in the absence of clinical or obvious signs of ischemia, ST should be prolonged to the point of maximum voluntary fatigue, and not set the target to reach 85% of the EMHR. Finally, it must be taken into account that, in order to assess the HR response during exercise, the test should be performed in the absence of beta-blockers.

Recovery of heart rate

When the HR at the minute of the end of the ST has not decreased by at least 12 bpm with respect to the maximum value obtained, there is an insufficient recovery[185]. This data is indicative of a possible autonomic dysfunction and has been associated with insulin resistance in young adults[202]. In addition, it is an independent predictor of risk of all-cause mortality in cases of ischemic heart disease in women[203].

Risk indexes

The use of risk indexes that integrate several parameters obtained in ST has proven to be a useful tool in the diagnosis of cardiovascular events. One of the most used is the Duke Index (DTS, Duke Treadmill Score), obtained from the total time of ST, changes in the ST segment and the appearance of angina[204,205]. Depending on the results obtained, it is possible to stratify the level of risk and improve the diagnostic and prognostic accuracy of ST[83,204,205], although it is probably less effective in elderly women[206]. It has also been observed that the survival of women seems to be better than that of men at all levels of the Duke index[204,205].

According to the WOMEN study (What is the Optimal Method for Ischemia Evaluation in Women?)[207], the ST performed on women with good exercise capacity and with an assessable ECG have the same predictive value as the myocardial perfusion studies, and therefore are a cost-effective diagnostic tool that should be taken into account in initial test batteries to be performed in symptomatic women with suspected coronary heart disease.

As for the falsely positive ST in women, it is likely that a large part of them are due to the presence of syndrome X. This syndrome is characterized by chest pain and electrocardiographic changes in exercise without evidence of coronary disease by angiography[208,209] . Although its prognosis is better than that of women with evident obstructive coronary disease, it is often associated with an increase in cardiovascular mortality and, therefore, it needs to be taken into account in assessing women with persistent chest pain and falsely positive ST.

Conclusions

In conclusion, compared with the male population, ST in women presents some limitations in its performance, evaluation and prognostic significance and diagnosis, which must be taken into account. The remaining unresolved question remains the high number of falsely positive results based on the interpretation of ST segment depression, possibly due to a higher prevalence of non-obstructive coronary disease in women. However, given the low cost of effort ECG and its efficacy compared to other diagnostic options, ST can help guide clinical decisions and be an optimal and cost-effective choice test, especially in symptomatic women. Table 14 shows the AHA recommendations and levels of evidence for the use of ST in ischemic heart disease in women[185].

Table 14. Recommendations regarding the use of stress tests in women with suspected ischemic heart disease.

- The stress test is the diagnostic test of choice in the case of symptomatic women with normal resting ECG and with functional capacity above 5 MET, reserving the imaging tests for those cases of basal ST segment abnormalities or inability to perform efforts (class I, level of evidence B).
- The interpretation of the stress test should include not only ST segment assessment, but also exercise capacity, chronotropic response, HR recovery and BP response during exercise (class I, level of evidence B).
- In those cases with anomalous or inconclusive results in the stress test (for example, negative ECG in a submaximal test or with an inability to reach 85% of the theoretical value of the predicted maximum HR), the study must be completed with tests diagnostic imaging (class I, level of evidence C)

Modified from AHA[185].

Stress test in children

The indications for ST in the pediatric age group are broad and have as general objective the evaluation of physical capacity and mechanisms that limit or may limit exercise. In addition, children and teenagers who participate in high-profile competition activities are increasingly numerous and therefore require a thorough analysis of their physical condition.

However, ST in the pediatric population has some differential characteristics that it is essential to take into consideration, both in the healthy child and in the sick child. Before performing the test, it is very important that both the child and the parents or guardians fully understand the procedure to be performed. In addition, the physiology laboratory must be equipped with material appropriate to the child's age and size (pressure cuffs, pediatric masks, suitable ergometers, etc.) as well as safety measures and emergency protocols adapted for this population (Pediatric CPR team).

Ergometers

Each case should be assessed individually according to the child's size and age, level of coordination, physical condition, purpose of the test and the specificity of the sport. The use of the treadmill is generally preferred, which is considered safe even for children aged 3-4 years[210,211], although the use of a safety harness may be necessary. The cyclergometer provides more stable physiological measurements during exercise and is preferred when the goal is to prioritize the measurement of BP, ECG or echocardiographic measurements. However, some children, especially children under 6 years of age, may have difficulty maintaining a constant pedaling rate, even when the cyclergometer adjusts to their size[210], making it more difficult to achieve maximum effort due to premature fatigue[211].

Protocols

There is a great heterogeneity in the choice of exercise protocols[51], which should ultimately be done according to the characteristics of the child, the purpose of the test, the variables to be measured and the available material[211,212]. Ideally, the protocol should be designed to reach the maximum limit in 10 ± 2 minutes, with an initial period of data collection at rest, a pre-heating of 2-3 minutes and a recovery period of 5-10 minutes[210,211] . Table 15 shows the protocols commonly used in pediatric cardiology and physiology. Some of them, like Bruce's, are of dubious application in children (especially in the smallest or with little physical capacity), so it is advisable to use modifications of the same with smaller increases of the load, or to choose other alternatives.

Ramp protocols are a good option as they provide better haemodynamic response and gas exchange than protocols with longer steps. The most recommended is the use of continuous or ramp incremental protocols, whose load increase is adjusted to the optimum duration of the test. A good estimate[129] of this slope is W/min = (predicted VO_2max - VO_2 rest) / 92.5. Generally speaking, the increase in workload

Table 15. Stress protocols used in children.

Protocol	Applications
Multiple staggered protocols. Treadmill: Cyclergometer: Bruce James Balke McMaster Cornell Strong McNaughton Godfrey	Measurement of VO_2max, AT and maximum power. Analysis of the causes of exercise limitation. Evaluation of myocardial ischemia or arrhythmias.
Continuous incremental protocols with increments of 1 minute or ramp	The same. Measurement of work and ventilatory efficiency.
Constant load protocols	Submaximal measurement of ventilatory parameters or HR. Analysis of the effect of a therapeutic intervention or the energy cost of daily live activities.
Sprint protocols	Study of exercise-Induced Bronchospasm
6-minute walking test	Assessment of exercise tolerance in children with moderate to severe limitations

Modified from Paridon *et al*.[210].

for teenagers in good physical condition can be 20-25 W / min, while for smaller children or with greater limitations it will be 5-10 W / min. Some authors propose for healthy children an increase in workload in relation to body weight, with increases of 0.25 W / min per kilo of weight[213].

Other protocols used are the 6-minute walking test[144], indicated to evaluate exercise tolerance in children with moderate to severe impairment, in whom ST may be too demanding or specific protocols depending on the objective, such as the bronchospasm provocation test. In this case it is preferable to use a treadmill versus a cyclergometer, since the type of exercise is more likely to induce bronchospasm. Protocols of 5-8 minutes of exercise are used at a high intensity, around 80% of the maximum capacity, load to be reached within a maximum of 2 minutes, and with a brief warm-up period to avoid refractoriness in the development of bronchospasm[210].

In any case, regardless of the protocol and ergometer used, in the tests with analysis of ventilatory gases, special care must be taken to ensure that the nozzle or mask is correctly adjusted. Masks are usually more suitable because they allow more natural breathing, both through the mouth and nose, and avoid the nasal clip, which is poorly tolerated by children. In younger children and those with severe restrictive lung disease, the dead space of the system should be avoided.

Criteria of maximality

It is estimated that between 20% and 40% of children or teenagers do not present the typical VO_2 plateau at maximum level[212,215,216], and therefore, in both trained and untrained children, it is preferable to use the VO_2 peak and to use other criteria to establish the maximality of the test[210,216,217]:

- Respiratory quotient greater than 1 or 1.1, according to the authors.
- HRmax close to 200 bpm during ST in tapestry or at 195 bpm on cycleergometer, or a heart rate within 85-95% of the maximum predicted for age. Keep in mind that in children with chronotropic insufficiency or other limitations to exercise this value can be difficult to reach.
- Lactate level in blood ≥ 6 mmol / l.

Some authors, however, consider that the use of secondary criteria may condition the acceptance of a lower than actual peak VO_2, or reject a true VO_2max measure in untrained children[212]. Therefore, it is important to also take into account the subjective criteria of the experienced examiner[210], and in case of doubt, perform supramaximal tests after the first measurement of VO_2max to confirm their values[216].

Interpretation of results

Age, sex, puberty, physical condition and the growth process itself substantially affect the physiological response to exercise. Therefore, in order to avoid erroneous interpretations, both excess and default, it is necessary to adjust the data obtained in the ST according to the child's maturational state and its special characteristics.

A study on the validity of pediatric reference values shows that there is a great heterogeneity in the choice of exercise protocols and adjustments made in relation to the child's size, which makes it difficult to find a broad set and reliable reference values for children[51]. This contributes to a great extent to generate doubts in the interpretation of the results, a fact of special importance in the evaluation of children and teenagers with congenital heart diseases, in which the objective study of the intolerance to the exercise is a crucial complement for the clinical evaluation.

In general, reference values are expressed in a non-parametric format, in which a variable is presented as a mean and its standard deviation according to various subgroups (age, sex, etc.), or can be adjusted by means of a mathematical regression based on one or several factors of influence. The most common is to use prediction equations that take into account size (instead of weight), although these equations may not be suitable for tall children with a body mass index (BMI) of less than 18 kg/m^2 or for children with low size[218,219]. It is probable that weight, height or age play a separate role in the explanation of VO_2max, and thus normalization based on a single variable (for example, the child's weight) may generate an inadequate or incomplete data[51,220,221]. Therefore, given the lack of adequate reference data, it is advisable the interpretation of the results obtained in the ST, taking into account the prospective studies of specific population groups and protocols, assuming that the evolution of the parameters during the development of the child does Is not linear and is likely to influence more than one variable[51].

Variables

As in adults, ST can be performed with or without ventilatory gas analysis. A ST with ECG monitoring may be sufficient for the study of BP, electrocardiographic changes or SaO_2, or when the child does not tolerate the mouthpiece or ventilator sampling mask. In these cases, the indicative parameter of the capacity of effort will be the time until the fatigue in treadmill, or the peak of power in cyclergometer. However, the range of normality of these variables is very wide in children, so its usefulness is limited. In addition, if they exist, they provide little information about the cause of a possible exercise intolerance. Therefore, whenever possible, and in both the healthy and the sick child, it is preferable to use ST with gas analysis. Table 16 shows a list of the main variables to be analyzed and their usefulness in different heart diseases in children[211].

Children with heart disease

ST is used in the diagnosis and prognosis of CVD and respiratory diseases in children and teenagers and is considered a safe procedure even in high-risk children[210]. Unlike to what happens in adults, ischemic heart disease is uncommon in children and therefore the main indications for ST are the evaluation of functional capacity and the identification of arrhythmias or other anomalous responses induced by exercise[211]. The ST also allows objective information to be obtained for decision-making, evaluation of treatment efficacy and definition of individual safety limits[222,223]. In addition, it instills confidence in the child and family, and encourages patients to participate in physical activity programs that improve their functional capacity.

The most prominent situations in pediatric cardiology in which ST are performed are congenital heart disease, acquired heart disease or cardiomyopathy, and others that are discussed below.

Congenital heart disease

In children with congenital heart disease, it is recommended that a maximum ST be achieved (or as close to the maximum as possible) in order to assess their physical capacity and perform an individualized prescription of physical activity. The HRmax in this context is not a valid indicator of maximality, since many congenital heart defects are accompanied by a certain degree of chronotropic insufficiency that prevents reaching maximum values of HR[224], so other criteria should be considered, as mentioned previously.

Table 16. Variables to be studied in the stress test in children.

Variable	interpretation	Indications
Peak VO_2	↓ In low physical condition or cardiorespiratory insufficiency	Congenital heart disease, cardiomyopathy, pulmonary hypertension, cardiac transplant recipients, complete AVB.
HRmax	↓ In chronotropic insufficiency	Congenital heart disease operated, Long QT syndrome, heart transplant.
	↓ In the treatment with beta-blockers	Congenital heart disease / cardiomyopathy with heart failure, arrhythmias.
ECG	Exercise-induced arrhythmias IIschemia	Congenital heart disease, primary arrhythmias, Kawasaki disease, coronary anomalies.
	Other changes induced by the exercise	Long QT syndrome, Brugada syndrome, WPW, markers.
O_2 pulse	↓ In ventricular dysfunction	Congenital heart disease, cardiomyopathy, fontan disease.
SaO_2	↓ In lung disease, intracardiac or intrapulmonary shunt	Congenital heart disease.
BP	↓ In systolic dysfunction ↑ In AHT	Congenital heart disease, cardiomyopathy (hypertrophic, especially), aortic coarctation.
Anaerobic threshold	↓ In low physical condition or cardiorespiratory insufficiency	Congenital heart disease, cardiomyopathy rehabilitation programs.
VE/VO_2 VE/VCO_2 slope	↑ In situations of ineffective ventilation (disturbances of ventilation / perfusion)	Congenital heart disease with right or left heart failure or shunt, operated fallot, pulmonary hypertension, heart transplant recipients
Pulmonary function test	↓ In the presence of lung disease added	Congenital heart disease with multiple thoracotomies, right-to-left shunt, ventilation / perfusion alterations

Modified from Massin *et al*[211].

In general, physical activity guidelines in children with congenital heart disease are of limited value to most patients because they focus primarily on competitive sports and base the decision-making process on individual anatomical injuries. A more appropriate approach would be to formulate recommendations based on the dynamic study of hemodynamic and electrophysiological variables[223]. In this approach, ST can help provide an individualized recommendation based on the interpretation of VO_2 peak, HRmax, Borg scale, BP response to exercise, oxygen saturation and detection of rhythm disorders and of the conduction during the physical activity[223]. These data is also of interest for the evaluation of clinical status in patients potentially candidates for cardiac transplantation[225].

Children with acquired heart disease or cardiomyopathies

In these cases, in addition to assessing effort tolerance, BP response and electrocardiographic alterations, AT and VO_2 peak determination are of interest. These data provides interesting information for the assessment of the severity of heart failure, the progression of the disease and the efficacy of the treatments. VO_2 peak has been shown to have prognostic value in children with dilated cardiomyopathy, in whom morbidity and mortality increase when the value is less than 62% of the theoretical[226]. The VO_2 also serves as a reference for deciding the right time for a possible heart transplant.

In hypertrophic cardiomyopathy, an annual ST is recommended in order to assess the risk of sudden death, which among other factors is associated with an abnormal BP response. In addition, ST can also provide diagnostic information in primary metabolic cardiomyopathy due to the detection of severe acidosis.

Other situations

Although myocardial ischemia is rare in children, it is important to note that some basal ECG anomalies (conduction abnormalities, juvenile ST patterns, etc.) can be confused with exercise-induced ischemic changes and decrease, even in the case of potentially ischemic heart disease, the sensitivity and specificity of ST to detect ischemia. Therefore, if after a ST, is suspected of having ischemic heart disease in children, it is necessary to confirm the diagnosis through other tests, such as cardiac effort echography or perfusion tests[227,228].

On the other hand, chest pain is a relatively frequent symptom in pediatrics, although it is rarely of ischemic origin and is more commonly associated with asthmatic problems. In these cases, a spirometry before and after exertion will be the priority test to be performed. However, when there is a clinical or exploratory suspicion that the pain is of ischemic origin, and since exercise ECG has little diagnostic value for ischemic heart disease in children[229], additional tests will be necessary to confirm the diagnosis[227,228].

ST may also be useful in the management of arrhythmias in children. In general, the onset of cardiac arrhythmias during exercise is considered to be a risk factor. As for the presence of ectopic beats, their disappearance during exertion is a sign of benignity in structurally healthy hearts[230], but not in the case of structural alterations, in which they have little prognostic value[231]. ST can also be used as a support in the diagnosis of catecholaminergic polymorphic ventricular tachycardia[232], long QT syndrome[233,234], and Brugada[232,234] syndrome, among other conditions.

Stress test for the elderly and people with disabilities

Stress test in older people

The age at which an elder or elderly person is considered is 65, and for the correct use of ST, it is necessary to know the changes associated with age in the aerobic response and also in the pathologies associated with that same age, mainly in relation to CVD[3, 235-237].

The reason for performing an ST in healthy elderly is similar to that considered for the adult population in the same health conditions[1,238].

The ST would be indicated to prescribe exercise in EPOC patients and that they will carry out an exercise program as rehabilitation[239-241], and in those with peripheral vascular disease who also carry out exercise programs such as rehabilitation[242,243].

As a general rule, the elderly need a longer adaptation time for a work intensity[244]. In addition, in this population, it should be taken into account that resting HR is usually decreased or unchanged from adults[238], but the elderly have limitations to raise it with exercise, which makes it difficult to achieve HRmax.

SBP increases throughout adulthood due to progressive arterial hardening[245], while DBP stabilizes in the 60s and then decreases. The response of SBP to maximal and submaximal exercise increases with age, and this occurs in a more pronounced way in women[246].

VO_2max decreases by about 10% per decade of age, from late youth in women to mid-20s in men. This decrease is associated with a decrease in cardiorespiratory endurance activity. The HRmax also decreases with age, approximately one beat per year, as discussed above. These changes are smaller in older athletes who have continued to exercise, which indicates that physical inactivity is closely linked to these changes occurring in the age group[247].

Numerous diseases common in the elderly may limit the ability to perform ST, such as EPOC, commonly associated with CVD, or osteoarthritis, as well as obesity, which are highly prevalent at these ages. In addition, mental health problems and cognitive impairments must also be taken into consideration[248]. All this, together with the lack of habit of vigorous exercise or the fear of apparatus, usually results in the realization of submaximal ST.

Both the treadmill and the cyclergometer are used for the realization of the maximum ST. The treadmill is preferable, except logically in people with changes in walking or sight, although muscular fatigue appears more prematurely in the cyclergometer [249].

The test should last between 8 and 12 minutes, and power increases should be small and frequent to avoid physical and psychic fatigue.

Therefore, protocols that maintain constant tape speed and increase lift, such as those of Naughton or Balke, are preferable to the usual Bruce. Likewise, ramp protocols with small power increments of 0.5-1 MET per stage are preferred in the cyclergometer. Likewise, it is advisable to perform a warm-up phase of about 2-3 minutes to improve the patient's anxiety and avoid muscle problems[249,250].

Age may increase the risk of ST on supraventricular or ventricular extrasystoles even in asymptomatic individuals, but it does not appear to increase the risk of heart attack or death during the test[250,251].

ST is a good method to assess the progression of CVD and myocardial heart attack in these patients. With the data we have, the value of ST is similar in prediction to that of other populations[252]. In general, after a heart attack, the inability to perform ST indicates a high mortality risk. There are studies confirming an increase in 1-year mortality in those patients who were unable to perform post heart attack ST, as well as in those with a lower SBP increase during exercise (≤30 mmHg)[253,254].

In patients with stable CVD, ST has great diagnostic and prognostic utility[255,256]. Several studies have shown that ST alterations have a great predictive capacity in elderly patients[257,258].

Although the systematic use of ST in healthy elderly patients is not recommended, this test has a great prognostic capacity in this population[259,260].

Information on the usefulness of ST in patients older than 75 years is limited, but existing data suggest that it may have the same value as in younger patients, as indicated by several studies of ST in elderly patients[261,262].

Because of its simplicity, low cost and extended familiarity in its realization and interpretation, ST in treadmill with electrocardiographic control is the best test for the selection of elderly individuals with normal ECG who want to perform exercise[263].

The indications of ST in the elderly, according to the Spanish Society of Cardiology[1], are:

- *Class I:* none.
- *Class IIa:* elderly people with chronic diseases who can benefit from individualized exercise prescription within a rehabilitation program
- *Class IIb:* assessment of the elderly with multiple risk factors.
  Assessment in symptomatic men and women over 65:
  - They want to start performing a vigorous exercise (intensity greater than 60% of VO_2max and especially if they are sedentary).
  - Have chronic diseases that pose a high risk of coronary diseases (diabetes, chronic renal failure, etc.).
- *Class III:* systematic screening in asymptomatic elderly.

Stress test in people with disabilities

There are ST protocols for people with physical disabilities[264], especially with hemiplegia, paresis after a vascular cerebral accident (VCA) or others with spinal cord injuries. These protocols employ arm ergometers and also cyclergometers. The test begins with power of 20 W and is increased by 10 W per step.

Both the protocols and the criteria for detention of the ST are similar to those of persons without disabilities, but the submaximal and discontinuous protocols will be of choice, as they are safer and similar to the daily activity.

HRmax will be 10-20 bpm lower than that achieved in legged ST, so the estimated HRmax will be reduced by those values.

In healthy people without upper limb training, the VO_2max reached in arm ergometers is only 50-70% of that reached in cyclergometers. Likewise, for any submaximal intensity value VO_2 is higher, and the increase in HR and BP is faster in upper limb exercise than in lower limb exercise[265]. For this reason, the sensitivity of ST with an arm ergometer to detect ischemic heart disease will be lower than that offered by the legs[265].

The clinical or functional ST of wheelchair users may be performed on crank ergometers, wheelchair ergometers or with the wheelchair itself on a treadmill.

The indications of ST in people with disabilities will be the same as in those without disability, maintaining the same subgroups: asymptomatic, athletes and cardiopathy[1].

Unfortunately, the limitation of exercise capacity in these tests makes them inadequate for the detection of abnormal responses, in which case pharmacological stress tests[3] will be preferable, although some studies question this thesis and give more specificity to the tests Physics[266].

In recent years there have been works in which people with intellectual disabilities perform ST in treadmill with maximum and submaximal protocols[267-269]. It is important that these people have some training in the protocols to be able to perform the test.

The maximum incremental test starts with a speed of 4 km/h for 2 minutes, to increase every 5 minutes by 2.5% the slope to reach 7.5%. From that moment it is increased every 2 minutes another 2.5% until reaching a maximum slope of 12.5%. From then on, the slope will be constant and the speed will increase 1.6 km/h to exhaustion. The recovery will be done for 3 minutes at 2.4 km / h with a slope of 2.5%[270].

The values of VO_2max in people with Down syndrome are lower than those observed in patients with other intellectual deficiencies and those of the general population[271].

Stress test in people with pathology

Stress test in cardiovascular diseases

CVD remains the leading cause of death in Spain. The early diagnosis and management of risk factors are the main strategy to combat them.

Just as valvular pathologies and cardiomyopathies have a diagnosis based on imaging techniques, ischemic heart disease and arrhythmias have an electrocardiographic diagnosis, and ergometry is one of the tests that can most early diagnose coronary disease.

In general, ST in patients with CVD has the following objectives:

- Diagnosis of ischemic or arrhythmic cardiovascular alterations, through electrocardiographic or echocardiographic criteria.
- Functional study, to establish a prognostic stratification and to individualize the treatment, including indications of cardiac transplantation.
- Study of parameters directed to the prescription of physical exercise within programs of cardiac rehabilitation or directed to the activities of daily life.

Among the CVD, three main areas of application of ST are: ischemic heart disease, arrhythmias and valvular diseases.

Ischemic heart disease

Ischemic heart disease is one of the most important diseases due to its impact on global mortality, although in recent years mortality due to ischemic heart disease has decreased in Spain[272]. Hence, the need to continue prevention, early diagnosis and treatment, and to control risk factors (hypertension, dyslipidemia, obesity, diabetes, smoking) and the imbalances between myocardial demand and the contribution of myocardial VO_2, distinctive of coronary disease.

Although the main utility of ST in ischemic heart disease is in the diagnosis, accompanied by clinical data, biomarkers and imaging techniques, ergometry also plays a prominent role in functional evaluation, prognostic stratification and physical exercise prescription in the coronary patients by incorporating measurement of VO_2max and AT through spirometric variables[1,272].

Diagnosis of coronary heart disease

The decision to perform a ST with a diagnostic character in coronary patients requires a prior evaluation of the likelihood of the patient suffering from ischemic heart disease according to age, sex and symptoms (Table 17).

The indications of a ST for diagnostic purposes are as follows:

- *Class I:* initial evaluation of patients with intermediate probability of coronary disease.
- *Class IIa:* patients with vasospastic angina and patients with symptomatic suspicion of coronary disease with minor changes in basal ECG.
- *Class IIb:* asymptomatic patients with additional risk factors.
- *Class III:* patients with significant alterations of basal ECG (pre-excitation syndrome, ventricular pacemaker rhythm, ST depression greater than 1 mm, LBBB).

In healthy adults, ST has an indication of class IIb in the assessment of people with multiple risk factors and asymptomatic men over 45 years and women older than 50 years who wish to begin vigorous exercise, especially if they are sedentary, or have a high risk of ischemic heart disease (chronic renal failure, renal transplantation, diabetes with peripheral vasculopathy).

Protocol of stress test in coronary patients

The protocols for ST in these patients differ depending on whether the VO_2max can be measured directly or indirectly, in which case standardized protocols should be used in which METs are calculated depending of the stage reached during the test.

When the measurement of VO_2max is performed directly by ergospirometry, the most adequate protocols are those in ramp that allow to reach the maximality and to calculate the thresholds in a more precise way.

The Bruce protocol is one of those used in sedentary people and in cardiac patients. It varies both the inclination and the speed of the treadmill, and the VO_2max is estimated indirectly. In addition to the electrocardiographic control, in this protocol control of BP is done.

The modified Bruce protocol is a variation of Bruce's with less intense stages (velocity, inclination). It is more suitable for the adaptation to the treadmilll of the subjects with less physical capacity (Table 18).

The ergometric bicycle protocols are mainly used in ST with echocardiographic control[2,273]. Some formulas can be used to estimate VO_2, such as the American College of Sport Medicine (ACSM)[238]:

$$\mathbf{VO_2\ (l/min) = 0.0108 \times power\ (W) + 0.007 \times Body\ weight\ (kg)}$$

This cyclergometer protocol starts with low resistances (25-50 W) and increases the load every 2 minutes by 20-25 W until the target is pursued, maximum or submaximal.

ST in cyclergometer have the following advantages in relation to those made in treadmill[2]:

Table 17. Probability of ischemic heart disease.

Age (years)	Gender	Typical Angina	Non typical pain	Non angina pain	Asimptomatic
30-39	Male	Intermediate	Intermediate	Low	Very low
	Female	Intermediate	Very low	Very low	Very low
40-49	Male	High	Intermediate	Intermediate	Low
	Female	Intermediate	Low	Very low	Very low
50-59	Male	High	Intermediate	Intermediate	Low
	Female	Intermediate	Intermediate	Low	Very low
60-69	Male	High	Intermediate	Intermediate	Low
	Female	High	Intermediate	Intermediate	Low

High: higher than 90%; intermediate: 10-90%; low: lower than 10%; very low: lower than 5%

Table 18. Modified Bruce protocol on treadmill[42].

Stage	Time	Speed	Inclination	MET
1	3	2.7	0	1.7
2	3	2.7	5	2.8
3	3	2.7	10	5.4
4	3	4.0	12	7.0
5	3	5.4	14	10
6	3	6.7	16	13
7	3	8.0	18	17
8	3	8.9	20	20

- Increased stability in ECG recording.
- Greater ease of control of BP.
- Lower cost and space.

Table 19 shows the parameters evaluated in the diagnostic ergospirometry.

All these measures must be controlled from the resting phase prior to the start of the test until the end of it. Electrocardiographic, BP and symptom control should be maintained during the recovery phase, as symptoms such as angina, BP lowering or arrhythmias may appear, and in addition, if electrocardiographic abnormalities have been observed during the test , the time it takes to normalize with a prognostic purpose must be controlled.

Reasons for completing the test

The ST ends when the fatigue level, which prevents further effort in the maximal tests is reached, in order to obtain variables of maximum capacity or functionality, such as VO_2max, HR and maximum BP, and maximum velocity or W. In submaximal tests, the objective is to determine responses or variables in intermediate intensities for the control and follow-up of treatments, training, etc.

The absolute criteria for completion of the ST are[1,2,273]:

- Repeated desire of the subject to finish the test.
- Progressive precordial anginal pain.
- Decrease or lack of increase in SBP despite increased load.
- Severe or malignant arrhythmias: tachycardic AF, frequent, progressive and multiform ventricular extrasystoles, ventricular tachycardia, flutter or VF.
- Central neurological symptoms, such as ataxia, dizziness or syncope.
- Signs of poor perfusion: cyanosis, pallor.
- Bad electrocardiographic signal that prevents the control of the path.
- The relative criteria for completing the ST are:
  - Striking ST segment or QRS complex changes (major axis changes).
  - Fatigue, tiredness, dyspnea and claudication.
  - Non-severe tachycardia, including supraventricular paroxysmal.
  - Branch block that simulates ventricular tachycardia.

Table 19. Parameters evaluated in the diagnostic ergospirometry.

Electrocardiographic parameters:
- ST-segment depression
- ST-segment elevation
- Arrhythmias and conduction disturbances

Hemodynamic parameters:
- Cardiac frequency (according to ECG)
- PA taken at the beginning, at the end and at the end of each stadium
- Double FC xPAS product

Ventilatory parameters:
- VO_2
- Production of CO_2
- VE
- Metabolic equivalents (VO_2/VE;VCO_2/VE)
- Breathing rate

Clinical Parameters:
- Angina
- Ventricular dysfunction (dizziness, paleness, cold perspiration, cyanosis)
- Dyspnea and claudication
- Subjective effort perception

Parameters of functional capacity:
- External work expressed in MET
- Exercise time

Interpretation of test results

Cardiology Interpretation

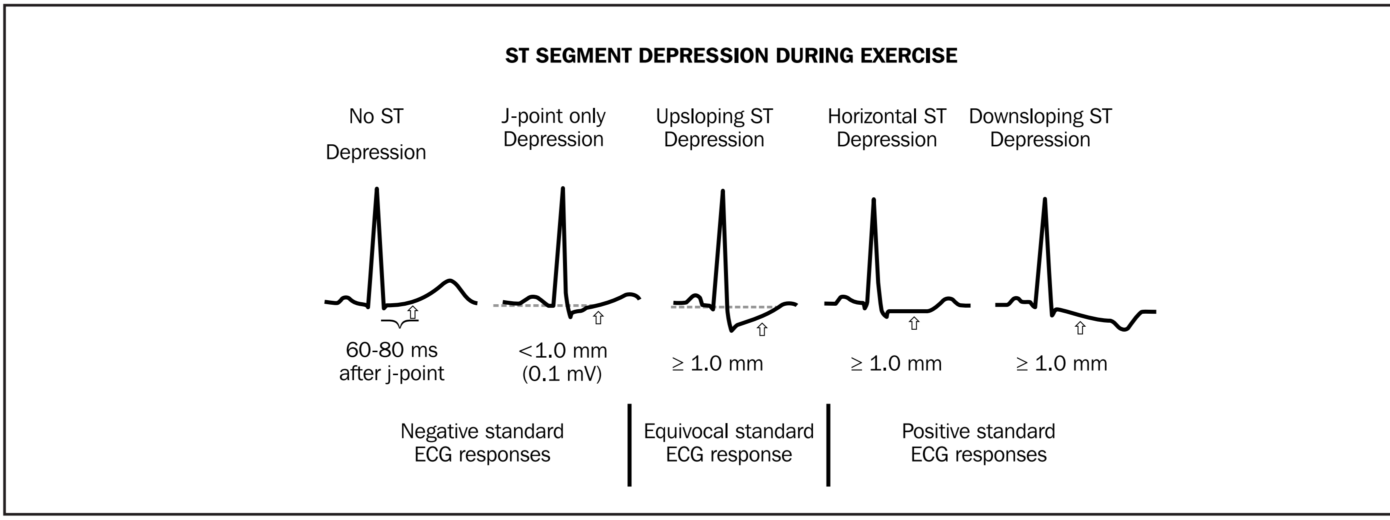
From the cardiovascular point of view, the criteria for abnormality of ST are the following[1,2,6,7,273]:

- Clinical:
  - Angina during ST.
  - Signs of left ventricular dysfunction (hypotension or lack of progression of BP, dizziness, paleness, cold sweat, nausea).
- Electrocardiographic (non-absolute criteria that must be qualified in the clinical context of each patient) (Figure 18):
  - A decrease of the J point, relative to the basal level, of 0.1 mV or more, followed by a horizontal ST segment or decreased at 60-80 ms.
  - A decrease of the J point, relative to basal level, followed by a slowly ascending ST segment that at 60-80 ms remains depressed at least 0.15 mV below the isoelectric.
  - Elevation of the ST segment more than 0.1 mV in the absence of previous necrosis (except in aVR).
  - U-wave inversion.

The limitations in the diagnostic interpretation of ischemic heart disease according to the electrocardiographic findings are:

- ST segment decreases in patients with LBBB are not assessable, and are not associated with ischemia.

Figure 18. Changes in the morphology of the ST segment and the J point, and its interpretation as a positive or negative response to ischemia during exercise. (Retrieved from AHA Scientific Statemtent[7]).



– In patients with RBBB, ST decline in V1-V3 is not associated with ischemia, but when observed in V4-V6 and II-aVF it does have a value as a sign of ischemia.
– In left ventricular hypertrophy with alterations in repolarization, ergometry has less specificity, without varying sensitivity, and a negative result does have the value to rule out ischemia.
– Treatment with some drugs may interfere with interpretation of results (digoxin, beta-blockers).

Table 20 shows the causes of false positives and false negatives in ST[1].

Functional interpretation

Coronary patients have a functional deficit that cannot be assessed by the parameters determined at rest, as in the case of the evaluation of the ejection fraction. Functional assessment is performed by determining the VO_2max, as a variable that reflects the functionality of the aerobic system, allowing an objective evaluation of the functional impairment of the patients and the effects of the treatment established[1,2].

In addition to the VO_2max, AT calculation allows the prescription and follow-up of the training in the patients of greater risk, as is the case of those with heart failure.

Ergo-spirometry offers the advantage of good reproducibility in a bloodless manner, which makes it an ideal test for follow-up of coronary patients.

According to MET metrics in ST, patients can be classified according to the ACSM and New York Heart Association criteria[274]. Tables 21 and 22 show the classification of the general population according to VO_2max and that of patients with heart failure according to the VO_2 values in AT.

Table 20. Causes of false positives and false negatives in stress tests[1].

False positives	False negatives
Electrocardiographic: - Basal ECG alterations - Conducting conditions - Preexcitation syndrome	Insufficient effort level: - Not reaching the submaximal HR - Musculoskeletal or vascular limitations
Cardiopathies: - Valvulopathies - Prolapse of the mitral valve - Myocardial diseases - Left ventricular hypertrophy - Pericardial diseases	- Persons physically trained (in submaximal stress tests)
AHT	Coronary origin: - Disease of a vessel. - Lesions of scarce-meaning. - Sufficient collateral circulation
Metabolic and electrolyte disturbances	Certain drugs: - Nitrates - Beta-blockers
Vasorregulatory alterations: - Hyperventilation - Ortostatic - Excessive exercise - Anxiety	Technical aspects of valuation: - Inadequate number of leads. - Interpretation error.
Effects of drugs (digital, diuretics, antidepressants, estrogens)	
Others: - Anemia - Hypoxemia - *Pectum excavatum* - Women - Defects of technical interpretation	

Clinical Interpretation

Angina

The presence of angina during ST is a sign that is related to pathology. The behavior of anginal pain along the ST is also important, since it provides additional information about the prognosis depending on the time of onset, the characteristics and the intensity of the pain, and the behavior with the increase or the decrease of the intensity of the effort[2,7,273].

Table 23 shows the characteristics of anginal pain according to its intensity and characteristics.

Dyspnea

One of the symptoms on which a differential diagnosis should be made is dyspnea. The differential diagnosis should be established between dyspnea of cardiological or respiratory origin. The ergospirometry allows to make this differentiation according to the following criteria and variables:

- Lung disease:
  - VO_2max reduced (less than 85%).
  - VO_2 at the threshold above 40%.
  - Reduced inspiratory reserve (less than 30% or 15 l).
- Heart disease:
  - VO_2max reduced (less than 85%).
  - VO_2 at the threshold above 40%.
  - Normal inspiratory reserve (greater than 30% or 15 l).

Table 21. Classification according to the maximal VO_2 values reached in the exercise test.

	Age	Low	Acceptable	Medium	Good	High
Men	20-29	<25	25-33	34-42	43-52	>53
	30-39	<23	23-30	31-38	38-48	>49
	40-49	<20	20-26	27-35	36-44	>45
	50-59	<18	18-24	25-33	34-42	>43
	60-69	<16	16-22	23-30	31-40	>41
Women	20-29	<24	24-30	31-37	38-48	>49
	30-39	<20	20-27	28-33	34-44	>45
	40-49	<17	17-23	24-30	31-41	>42
	50-59	<15	15-20	21-27	28-37	>38
	60-69	<13	13-17	18-23	24-34	>35

Table 22. Classification of patients with heart failure according to criteria of the New York Heart Association[274].

Type	Deterioration	VO_2 peak (ml/kg/min)	AT (ml/kg/min)
A	From none to little	>20	>14
B	From little to moderate	16-20	11-14
C	Moderate to severe	10-16	8-11
D	Severe	<10	<8

Table 23. Classification of angina pain according to intensity in exercise test[7].

Description	Level
Beginning of angina. Light, but recognized as pain to the effort previously felt by the patient	1
The same pain, but moderately intense, though bearable	2
Severe anginal pain that forces the patient to stop	3
Unbearable precordial pain. It is the most intense pain felt by the patient	4

If no symptoms are present during ST and the electrocardiographic response is negative, the prognosis is good, provided the appropriate METs for age and sex are reached.

Prognostic stratification

The prognosis of patients with ischemic heart disease depends on the myocardial damage caused and on the functional status of the aerobic energy production system[2,6,7,273,275].

The indications of ST with prognostic character are:

- *Class I:* patients undergoing initial evaluation of coronary heart disease.
- *Class IIa:* patients with coronary disease with unfavorable evolution.
- *Class IIb:* patients with coronary disease and ECG abnormalities, and clinically stable patients who are evaluated with some periodicity.
- *Class III:* patients with limited life expectancy from any cause.

ST results may show signs of poor prognosis because they reflect impaired myocardial response or early ischemic alterations. Signs of poor prognosis of ST are shown in Table 24.

Exercise prescription[2,6,7]

The prescription of physical exercise in ischemic heart disease must be individualized and precise, to avoid the risks of exercise at inappropriate intensities and to promote the greatest number of adaptations beneficial to the cardiovascular and overall health of the patient.

Indications of ST for physical activity counseling in post heart attack patients are:

- *Class I:* to prescribe physical activity.
- *Class IIa:* to evaluate cardiac rehabilitation programs.
- *Class IIb:* patients with abnormal ECG.
- *Class III:* patients with limited life expectancy from any cause.

The variables used for the prescription of exercise in patients with ischemic heart disease are derived from the values of maximality and those corresponding to AT, whose determination is more precise when using the equivalents of oxygen (VE/VO_2) and carbon dioxide (VE/VCO_2).

Table 24. Signs of poor prognosis in the stress test in coronary patients[1].

– Symptoms such as dyspnea or angina from the earliest stages of exertion.
– FC <100 bpm at the beginning of limiting symptoms.
– In relation to ST segment alterations:
– Beginning ST depression at HR <100 bpm or with a minor effort of 4-5 MET.
– Depression> 0.2 mV.
– ST depression lasting up to 6 min of recovery.
– ST segment elevation.
– U-wave inversion.
– Ventricular tachycardia.
– Decrease of BP > 10 mmHg that is maintained despite the increase in the intensity of the effort, accompanied by symptoms of low expenditure.

The prescription is made using the following variables:

- Oxygen consumption:
  - Percentage of VO_2max.
  - VO_2 at the threshold.
- Heart rate:
  - Percentage of HRmax.
  - Heart rate at the threshold (Figure 19).
  - Heart rate reserve (HRR).
- Effort perception scale (Borg scale).
- Speed of exercise.

Stress tests in arrhythmias

The adrenergic activation that physical exercise causes on the cardiac conduction system can trigger arrhythmias. ST is an adequate test to explore arrhythmias, within the diagnostic tests directed to this end[1,7].

Supraventricular arrhythmias

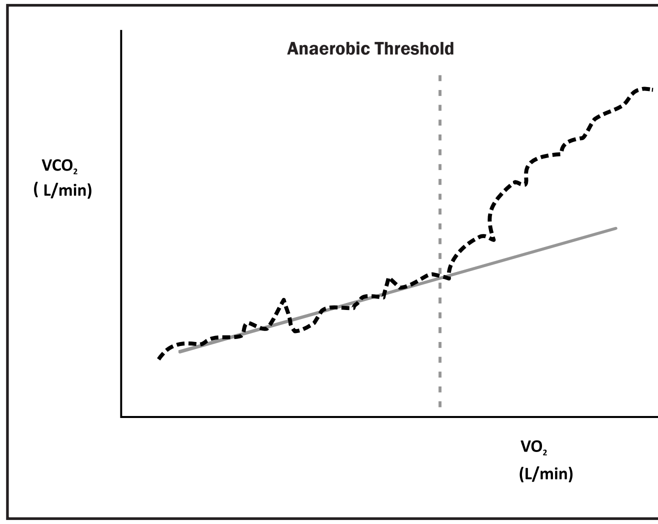
Paroxysmal palpitations may be induced by atrial or ventricular extrasystoles (which infrequently trigger tachycardia attacks), or by paroxysmal supraventricular tachycardias. In all these cases, ST has a very limited role and is only indicated in cases where it is assumed that arrhythmias may be induced by ischemia.

In WPW, ST is indicated when the diagnosis has been evidenced casually in a control ECG, without the existence of symptoms during exercise. In these cases, the disappearance of preexcitation is a sign of good prognosis.

Ventricular arrhythmias[2,6,7,275,276]

Physical exercise is a stimulus for the induction of ventricular arrhythmias in both asymptomatic subjects and in cardiovascular patients. Exercise-induced arrhythmias may be due to myocardial ischemia (in coronary patients or cardiomyopathies), in which case they are usually

Figure 19. Calculation of the anaerobic threshold according to the V-slope method[2].



accompanied by angina and ischemic ECG abnormalities, or non-ischemic changes related to adrenergic stimulation, such as idiopathic ventricular dysfunction tachycardia, or in long QT syndrome.

Bradiarritmias

Exercise can trigger second or third degree blockades, although these abnormalities are infrequent, and may be related to myocardial ischemia or to alterations of the infrahisian conduction system.

On the other hand, ST may be useful for the assessment of blockages and bradyarrhythmias induced by dysfunction of the sinus node or other pathways of the conduction system.

Indications of ST in patients with arrhythmias are:

- *Class I:* diagnosis of ischemic heart disease.
- *Class IIa:* induction of arrhythmias related to physical exercise. Programming of pacemakers with modulation of the HR and of automatic defibrillators.
- *Class IIb:* study of refractoriness in WPW in adult patients. Assessment of the efficacy of therapy. Study of the proarrhythmic effect. Study of ventricular arrhythmias triggered by hyperadrenergic states.

Valvular Diseases

ST has a relative value in patients with significant valvulopathies of different origins. In some cases ST is contraindicated, as in severe aortic stenosis. In the vast majority of valvulopathies, basal electrocardiographic alterations are observed, which prevent the diagnosis of ischemia, therefore, considering the diagnostic value of echocardiography in these patients, ST is relegated to very specific cases when ergospirometry is available, that allows functional assessment in patients with aortic stenosis and atypical symptoms, in patients with mitral stenosis to assess cardiac output when there is a discrepancy between the symptoms and the magnitude of the stenosis, and in mitral insufficiency to assess the surgical indication.

Indications of ST in patients with valvular disease are[1,2,7,273]:

- *Class I:* none.
- *Class IIa:* assessment of functional capacity in case of mitral stenosis.
- *Class IIb:* assessment of functional capacity in aortic valvulopathy and mitral insufficiency.
- *Class III:* diagnosis of ischemic heart disease in any valvulopathy.

Stress test in patients with hypertension

AHT is one of the most prevalent cardiovascular risk factors, estimated at 30-45% of the general population in Europe (according to the guidelines of the European Society of Hypertension (ESH) 2013[277], and it is the the main cause of stroke mortality in this continent.

The criteria for the definition of AHT are shown in Table 25 and the diagnostic evaluation of AHT is based on the measurement of BP in the resting consultation using a mercury sphygmomanometer and with the consented technique described by Mancia *et al.*[277], together with the measurement of HR, since this has been shown to be a cardiovascular risk factor for independent morbidity and mortality in patients with AHT.

BP self-monitoring (BPSM) at home and ambulatory BP monitoring (ABPM) are two methods that complement the information on the behavior of BP for the diagnosis of hypertension[1,277] (Table 26).

Table 25. Criteria for the diagnosis of hypertension.

Category	Systolic (mmHg)		Diastolic (mmHg)
Optimal	<120	or	<80
Normal	120-129	or	80-84
High normal	130-139	or	85-89
AHT grade 1	140-159	or	90-99
AHT grade 2	160-179	or	100-109
AHT grade 3	≥180	or	≥110
AHT isolated systolic	≥140	and	<90

Retrieved from Mancia G, *et al.*[77].

Table 26. Definitions of arterial hypertension according to blood pressure values in the outpatient and outpatient clinic.

Category	Systolic (mmHg)		Diastolic (mmHg)
BP	≥140	or	≥90
Ambulatory BP			
Day time (awake)	≥135	or	≥85
Night time/resting	≥120	or	≥70
BP of 24h	≥130	or	≥80
BP at home	≥135	or	≥85

Response of blood pressure during exercise

Changes in BP during exercise are due to increased cardiac output (elevating the SBP) and reduced peripheral vascular resistance (reducing or maintaining DBP)[278].

There are many discrepancies about the values that define a hypertensive response during exercise[1], the current reference value being that proposed in the latest ESH / ESC 2013 Practice Guidelines for Management of Hypertension[277], which define a hypertensive response when the values of SBP reached 210 mmHg in males and 190 mmHg in females[1,277]. In athletes, some authors have estimated the hypertensive response in SBP values of 250 mmHg and DBP of 115 mmHg[7,278], and it has also been proposed to relate the BP response to the stress intensity measured in MET. The values of normality are elevations of 7-10 mmHg for each MET of intensity of exertion, being the cutoff value > 11 mmHg / MET[279,280].

The stress test in the diagnosis and prognosis of hypertension

Although ST is not frequently used in the management of AHT, its use can provide information of interest in some specific indications:

- *Diagnosis of AHT in normotensive patients*[1,277,278]: ST is a useful technique to assess the risk of suffering AHT in normotensive subjects with a family history of AHT, in patients with labile AHT and in subjects with metabolic syndrome.
- *Diagnosis of AHT complications*[1,277-279]:
  - Ischemic heart disease: The main indication of ST in hypertensive patients is the diagnosis of ischemic heart disease, whose indications and methodology are the same as in normotensive patients[1,277]. A hypertensive response in patients with suspected coronary artery disease is a sign of lower severity, and even a good prognosis in elderly patients (older than 75 years), since it reflects good inotropic function. However, the hypertensive response in hypertensive young adults increases the long-term risk of causing heart failure and cardiovascular events[278]. A low BP elevation during exercise is considered a sign of poor prognosis for reflecting left ventricular systolic dysfunction.
  - Arrhythmias: Ventricular arrhythmias are common in hypertensive patients, especially when there is left ventricular hypertrophy. Malignant arrhythmias caused by silent ischemia increase the risk of sudden death[1,278]. Other factors that can trigger arrhythmias in hypertensive patients are hypokalemia and hypomagnesemia secondary to the use of diuretics.
- *Prognostic function:* ST is a useful prognostic indicator to evaluate functional capacity, electrocardiographic response and response of BP, which when it is abnormal must be supplemented with ABMP in order to establish a certain diagnosis.
- *Studies of functional capacity in hypertensive cardiopathy and for prescription of exercise.* In patients with hypertensive heart disease, decreased functional capacity in ST may reflect systolic or diastolic

ventricular dysfunction[277,278]. In hypertensive patients, the prescription of therapeutic exercise is based on the values of the functional capacity and AT, obtained in the ST, which are more precise when this is done with gas consumption measurement.

Evaluation and follow-up of treatment

ST can be used to evaluate the response to antihypertensive treatment, both pharmacological and lifestyle-based changes (exercise and nutrition). In these cases, variations in functional capacity and AT are evaluated in the ST.

Indications

The indications of ST in patients with AHT are[1,277]:

- *Class I:* diagnosis of myocardial ischemia.
- *Class IIa:* prescription of therapeutic physical exercise.
- *Class IIb:* diagnosis of AHT in prehypertensive situations. Diagnosis of AHT in borderline cases and assessment of functional capacity and treatment efficacy.

Contraindications

The contraindications for performing ST in hypertensive patients are the same as for other pathologies.

A BP of 240/130 mmHg is an absolute contraindication for ST, and values of 200/110 mmHg are a relative contraindication[1,277].

Protocols in the stress test[1,2,6,7,268,277]

One of the limitations for the use of ST in hypertensive patients and for the classification of patients is the lack of standardization of stress protocols.

The measurement of BP during ergometry is more accurate and easier to perform when using the cyclergometer. Regardless of the choice of the ergometer, the increments of the loads in these tests must be progressively slow, to reach the maximum load in about 10 minutes.

In addition to electrocardiographic recording and measurement of exhaled gas when an ergospirometer is available, BP should be measured before the start of the test, at the end of each exercise step, at the end of the test and in the first 3-5 minutes of recovery[1,2,6,278,280].

The taking of the BP during the effort should always be performed by well-trained personnel.

Exercise test in obese patients

The diagnosis of obesity is not a specific indication for the performance of ST. However, the cardiovascular, metabolic and musculoskeletal risks associated with obesity, together with the symptomatology that may accompany these patients, such as dyspnoea, mean that ST is indicated as a method of evaluation of cardiometabolic risk, of differential diagnosis of symptoms (dyspnea, precordial pain, dizziness, palpitations), for the evaluation of functional capacity and for the prescription and monitoring of physical exercise[2].

Diagnosis of ischemic heart disease

The indications of ST for the diagnosis of ischemic heart disease are the same as for adults with normal weight, although in these cases the presence of additional risk factors must be considered.

The indications are[1,273]:

- *Class I:* initial evaluation of patients with intermediate probability of coronary disease.
- *Class IIa:* patients with vasospastic angina and patients with symptomatic suspicion of coronary disease with minor changes in basal ECG.
- *Class IIb:* asymptomatic patients with additional risk factors.
- *Class III:* patients with significant alterations of basal ECG (preexcitation syndrome, ventricular pacemaker rhythm, ST depression greater than 1 mm, LBBB).

Special mention should be made of morbidly obese patients who will undergo bariatric surgery, given the risk of acute postoperative complications[281]. There is a proven relationship between preoperative functional capacity and postoperative complications in these patients, which has made that the AHA and the ACC have highlighted the usefulness of assessing through ST the functional capacity of patients with morbid obesity. The cut capacity is 15.8 ml/kg of VO_2, with the risk of CVA, thrombophlebitis, MI, unstable angina and upper death in those with VO_2max below this figure, which is a significant prognostic factor of complications[2].

Differential diagnosis of exertional dyspnea in the obese

Obesity is frequently associated with other cardiovascular diseases (AHT, coronary artery disease, arrhythmias), respiratory diseases (EPOC) and metabolic diseases (diabetes), as well as being associated with sedentary habits with decreased muscle component in body composition. Stress dyspnea is a frequent symptom in obese individuals, because the increase in body weight increases the energy expenditure for a given activity, increasing the VE / VCO_2. However, this symptom may also be due to the ventilatory overload that accompanies pathologies of the cardiovascular or respiratory system.

ST is useful for making this differential diagnosis (indication of class I), although it should always be accompanied by the data of the clinical history, blood analysis, spirometry, ECG and thoracic radiological study. Table 27 shows the differences between heart dyspnea (heart failure) and respiratory dyspnea (EPOC).

Evaluation of functional capacity and exercise prescription

The indications of ST for the prescription of physical exercise in obese patients are class IIa[1], and considering obesity as a cardiovascular risk factor can be indicated a ST with criteria similar to those applied in cardiology:

- *Class I:* differentiation between heart and lung disease as a cause of dyspnea, when it has clinical relevance for the patient.
- *Class IIa:* assessment of exercise capacity when indicated for medical reasons in subjects in whom the subjective assessment is not conclusive.

Table 27. Differentiation between dyspnea of cardiac and respiratory origin according to the ergospirometric variables

Variable	Cardiac (Heart failure)	Respiratory (EPOC)
VO_2max	Diminished	Diminished
Ventilator threshold	Diminished	Normal or diminished
Respiratory reserve	>20%	<15%
SaO_2	Normal	Diminished
FEV1 post-stress	Just as at rest	Greatly diminished in relation to rest

- *Class IIb:* evaluation of the patient's response to specific therapeutic interventions in which improved effort tolerance is an important goal. Determination of training intensity as part of cardiac rehabilitation programs.
- *Class III:* habitual use to evaluate the exertion capacity.

Aerobic functional capacity is an important prognostic variable in obesity. When comparing the prognostic value on mortality using different variables in obese patients, functional capacity has been shown to have a higher prognostic value than BMI[283].

As previously discussed, preoperative functional capacity in bariatric surgery is an important predictor of postoperative complications.

In addition to the evaluation of variables for exercise prescription, ST is used to control and monitor exercise programs, and in many cases it is earlier to change the functional variables, such as VO_2max, than in structural variables, such as fat weight[6,283].

Effort protocols

ST in obese patients should use protocols that allow maximum functional capacity to be achieved by reducing factors such as impact, to avoid early fatigue from overload and pain in the lower limbs. Safety precautions should be taken to avoid falls, given the possible instability during exercise in these patients.

The cycle ergometer is a safe tool and is always provided that patients can perform pedaling properly, although the test may be limited by early termination due to fatigue of the lower limbs.

Bruce treadmill protocols are also indicated due to maintaining speeds that allow walking by increasing the incline of the treadmill to avoid running impact, although they may trigger fatigue from overloading the leg muscles due to tilting. The use of treadmill increases the risk of falls in poorly adapted people, so it is often necessary to use handrails and support systems to prevent falls, although effort quantification is more inaccurate when manual support is required.

The precise determination of maximum functional capacity and ventilatory thresholds requires the use of ergospirometry with direct measurement of gas consumption. If it is not available, protocols such as Bruce on a treadmill allow to correctly estimate the VO_2.

Stress test in diabetics

Physical exercise can be considered, along with medication and diet, as one of the means available to the diabetic person to try to normalize the clinical and metabolic alterations of their disease[284]. In fact, the American Diabetes Association and the European Association of the Study of Diabetes recommend type 2 diabetics to practice 150 minutes a week of moderate to vigorous exercise to avoid complications[285]. In people with type 1 diabetes exercise is less important in glycemic control, but will always be beneficial in the prevention of cardiovascular risk[286].

Early manifestation of heart disease has been recognized as a complication of diabetes in adults[284,287].

ST is a good method of detecting CVD in asymptomatic diabetics[3,288]. These individuals have less aerobic capacity than non-diabetics of the same age.[289] Chronotropic response is decreased in ST even when there is no autonomic neuropathy[290]. Reduced HR recovery associated with adverse cardiovascular reactions can cause death[291]. Numerous studies report an inverse relationship between exercise capacity and mortality rate in diabetics, so that for each MET that lowers aerobic capacity increases the risk of death by 18% over the next 7.8 years[292].

Systematic STs are not indicated in diabetics without symptoms wishing to initiate light or moderate physical exercise[293], but they are recommended for those asymptomatic diabetics who initiate vigorous exercise[263], in men older than 45 years and in women over 55 years[294].

Stress testing in people undergoing treatment

Although in the area of SM, it is not expected to have to work with a high population rate under major cardiovascular medical treatments, since there is an increasing general population performing various forms of playful sports, and sometimes with a high competitive component, it is necessary to consider the possibility of having to perform ST in patients who are undergoing cardiovascular treatment[1].

The most common cardiovascular treatment situations are described below.

Beta-blockers

Beta-blockers do not prevent the morphological interpretation of a ST, but they affect the chronotropic response, limiting or even reducing the HR that is reached in ST and, therefore, the moment in which the electrocardiographic or clinical alterations appear[295].

Digital

The use of digitalis derivatives is becoming less frequent in patients on sinus rhythm, but it is frequent in those with AF in whom resting HR is controlled; however, it does not affect exercise HR (as do beta-blockers)[296].

As for morphology, if the impregnation is sufficient, there is a decrease in ST in many of the leads (called digitalis buccal), which may alter the interpretation of possible ischemic ECG changes during ST[297].

Amiodarone

Amiodarone has two types of influence on ST: a significant cushioning of HR, as with beta-blockers, although to a lower degree, and on the other hand the impregnation of amiodarone alters the repolarization morphology of the resting ECG, which may limit the interpretation of the same in the ST (prolongation of QT, flattening of bimodal T or T).

Nitrites, dihydropyridines and other vasodilators

In general, antianginal agents may cause electrocardiographic and clinical signs to be delayed in relation to the imposed load, which may alter the interpretation of ST. They can also moderate BP. Nitrites and dihydropyridines do not affect the development of HR with exercise, but diltiazem may induce HR braking, similar to beta-blockers.

Diuretics

Diuretics per se do not modify ECG behavior in a ST. However, a treatment (determined by its intensity or duration) with diuretics may alter electrolyte balance (magnesium, calcium, potassium), which can lead to an alteration in the ECG morphology and the appearance of arrhythmias or blockages (especially fascicular) with exercise. It is outside the scope of this section to detail such alterations, especially since their incidence is very scarce.

Pacemaker

More and more frequently, it is possible for a patient with an implanted pacemaker to do ST. From the electrocardiographic point of view, it is necessary to note some details:

- On the one hand, the limitations to the HR that impose the presence of a pacemaker stimulus. If the pacemaker is of variable frequency, type XXXR, and the patient is dependent on the pacemaker, the HR will be limited both above and below, according to the limits programmed in the pacemaker. If the patient is not dependent on the pacemaker, the HR will be limited only from below, but may increase to the HR that the patient's native conduction system allows.
- On the other hand, during the exercise, the morphology of the pacemaker stimulated beats will not be interpreted, whereas if its own beat appears in the tachycardia or effort rhythm, the morphology will reflect the changes expressed in the chapter 6 (The effort electrocardiogram) with all its characteristics and limitations.

In any case, before a ST in a patient with pacemakers, other parameters must be considered for their interpretation: thoracic pain, degree of physical fatigue (fatigue scales), respiratory quotient control, lactate control, etc.

Stent intracoronary prostheses or revascularization surgery

A ST in a patient who has undergone coronary revascularization, or angioplasty with (eventually) implantation of intracoronary stent prosthesis, may have some basal ECG alteration that must be taken into account when interpreting the ECG. In fact, ECG abnormalities during ST are also poorly reliable, and an electrically positive test with correct revascularization or a permeable stent can often occur. Therefore, in order to assess ST, it is necessary to use supplements (such as exercise echocardiography or isotopic tests) or non-electrocardiographic parameters (chest pain, physical fatigue rate, respiratory rate control, lactate control, etc.).

Stress test to support training

Previous considerations

Although the main objective of the ST in the athlete is to discard pathology that completely or partially contraindicates the practice of physical activity at different levels (competitive, recreational ...), estimation of shape, prescription of work intensities and the objectification of its evolution over time are other objectives that are especially useful for the athlete.

Although individual sports such as athletics or cycling may be the ones that benefit most from the data provided, also collectives such as football or basketball can be used to objectify the actual physical load of their specific training models from the data obtained in ST.

Depending on the type of ergometer and the test performed, different indicators of usefulness for training are obtained: HR, lactate production rates, maximum speed reached (also called maximum aerobic speed, MAV, expressed in km / h or T / Km) and MAP (expressed in W or W / kg).

Although STs performed with gas analyzers allow greater accuracy of the data, their complexity and high cost, as well as the discomfort of the analyzer itself, make the so-called indirect STs the most used, in this case using various formulas for the calculation of the VO_2max. Some of the most commonly used ergometers (treadmill and cycle ergometer) are mentioned below, although the data of the maximum load reached (MAV or MAP) is also used as a reference element.

Treadmill

$VO_2max = 2.209 + (3.1635 \times V)$[299], where V is the speed in km / h.

In the assessment of the same athlete in the laboratory and on the training track, with the same gas analyzer, the same VO_2max is obtained in bothdeterminations[300], although there are some problems regarding the relation of these maximum values and their application for guiding training intensities.

In treadmill tests, taking into account the concept of MAV defined as "the minimum speed at which the VO_2max is reached" [301], it may be the case that the VO_2max plateau occurs before the last load, so which, according to the aforementioned definition, the MAV would not coincide with the final speed reached[302]. However, given the frequency of indirect tests in which this plateau cannot be appreciated, and with the possibility of comparison with the field tests for training planning purposes, both concepts are identified as the final speed achieved as MAV. This criterion should also be applied to the tests in cycle ergometer in which the final power achieved with the maximum aerobic power is identified.

The second problem stems from the equalization of speeds between the laboratory and the field. In order to compensate for the effect of the air resistance on the ground, it has been proposed to increase the slope of the treadmill from 1% to 3%, without conclusive results. Another option is to correct the speed of the carpet based on the body surface in the frontal plane61, taking into account the increase of the "cost" of VO_2 through the classical equation proposed by Pugh[303]:

$$\Delta VO_2 = 0.00354 \times Ap \times V^3$$

Where ΔVO_2 is the supplementary VO_2 in l / min to combat air resistance, Ap is the athlete's surface in m^2 projected on the frontal plane = 26.2% of the body surface, and V is the wind speed in M / s.

With this increase, the equivalent final formula is:

$$VO_2 = 2.209 + (3.1633 \times V) + (0.00354 \times Ap \times V^3)$$

With this in mind, the velocities of the treadmill can be corrected to approximate those obtained on the ground.

Cyclo-ergometer

Sportsmen[304]:

$$VO_2max = [12 \times power\ (W)] + 350$$

General population and growth period[305]:

Men: $VO_2max = [10.51 + power\ (W)] + [6.35 \times weight\ (kg)] - [10.49 \times age\ (years)] + 519.3$

Women: $VO_2max = [9.39 + power\ (W)] + [7.70 \times weight\ (kg)] - [5.88 \times age\ (years)] + 136.7$

The effects of wind and slope cannot be compensated for on the cycleergometer, so the speed data cannot be transferred to the field. Therefore, the indicators for the training are basically the HR and the power in W. It is becoming increasingly common for the athlete to perform the test with his own bicycle by inserting it on a roller (Figure 20). In this way, in addition to using their exact measurements, they can even directly calculate the W with the power sensors integrated in the machine, so that their translation to the training is even more specific.

There are three basic utilities of the ST for training: first, the estimation of shape; second, the proposal of training intensities and the prediction of performance in competition; and last, monitoring the evolution throughout the training process.

The stress test in the evaluation of the state of shape

The VO_2 obtained, directly or indirectly, is the most referenced indicator to evaluate the fitness status, both in sedentary and athletes, although also the maximum load reached (MAV or MAP) is used for the same purpose.

In relation to the general population, there are diverse classifications of the state of form. It is useful the one published by the ACSM, which is presented in percentiles of VO_2max (Table 28).

In relation to elite athletes, Table 29 shows the reference values according to the sports modality.

The stress test in training planning, performance prediction and training load control

Training Planning

There are two fundamental parameters that the ST contributes: the HRmax and the maximum load (MAV or MAP)[306]. In addition, several studies have found a correlation between the percentage of VO_2 and the HRmax, which allows expressing the work intensities according to both parameters.

When establishing training intensities, these values are taken into account, as well as the HRR, understood as the difference between HRmax and basal HR.

Figure 20. Detail of an exercise test on the bicycle.

Table 28. Percentiles of state of form based on the maximum VO_2, according to age[139].

VO_2 maximum (women)						
Percentile	**20-29**	**30-39**	**40-49**	**50-59**	**60 or more**	**Level**
90	44.2	41.0	39.5	35.2	35.2	Very good
80	41.0	38.6	36.3	32.3	31.2	
70	38.1	36.7	33.5	30.9	29.4	Good
60	36.7	34.6	32.3	29.4	27.2	
50	35.2	33.5	30.9	28.2	25.8	Average
40	33.8	32.3	29.5	26.9	24.5	
30	32.3	30.5	28.3	25.5	23.8	Low
20	30.6	28.7	26.5	24.3	22.8	
10	28.4	26.5	25.1	22.3	20.8	Very low
VO_2 maximum (men)						
Percentile	**20-29**	**30-39**	**40-49**	**50-59**	**60 or more**	**Level**
90	51.4	50.4	48.2	45.3	42.5	Very good
80	48.2	46.8	44.1	41.0	38.1	
70	46.8	44.6	41.8	38.5	35.3	Good
60	44.2	42.4	39.9	36.7	33.6	
50	42.5	41.0	38.1	35.2	31.8	Average
40	41.0	38.9	36.7	33.8	30.2	
30	39.5	37.4	35.1	32.3	28.7	Low
20	37.1	35.4	33.0	30.2	26.5	
10	34.5	32.5	30.9	28.0	23.1	Very low

The relationship between diverse percentages of VO_2 and HR[307], which can be seen in Table 30, has been established.

The concentration of lactate (mmol / l) and VO_2 are other parameters also obtained according to the ST protocol used that, mainly the first one, are helpful to characterize the different types of training.

Departing from the maximum values obtained and the estimation of AT, work intensities can be proposed for the different functional areas. Table 31 presents a compendium averaged from the functional training areas from the MAV, AT and HRmax[308-311] data.

Performance prediction

By knowing the MAV a brand prediction in the athletic disciplines can be established, as shown in Table 32.

Training load control

The HRmax obtained in the ST serves as a point of support for models of quantification of the training load, among which the most used has been the classic of Bannister *et al.*[313], which is based on the so-called training impulse units (TRIMP, training impulse) using the parameters of HR, exercise time and HRmax:

$$TRIMP = (\% HRR \times T \times K)$$

Where HRR is the reserve HR, T is the time in minutes and K is a variable constant according to sex (men: 0.64 × e1.92 ×% HRR); Women: 0.86 × e1.67 ×% HRR); Where e = 2.718.

Later Foster *et al.*[314] modified it and established a simpler model based on the three-phase model of Skinner and Mclellan[143], which delimits three work zones. Zone I would be below ventilatory threshold VT1 (equivalent to <65% of HRmax) and multiplied by 1 every minute that remains in it; Zone II would be located between the thresholds VT1 and VT2 (65-85% HRmax) and would multiply by 2 every minute in this zone; And zone III would be above the threshold VT2 (> 85% FCmax) and multiply by 3 every minute in this zone.

The test of effort in controlling the evolution of the training process

The ST is a reliable method to objectify the evolution of the fitness, which allows the evaluation of the effects of the planned training.

Figure 21 shows the improvement of an athlete after 5 months of training evaluated with an indirect test on a treadmill before and after the training period. It can be seen that, after working time, the

Table 29. Maximum VO_2 values in elite athletes of various modalities[306].

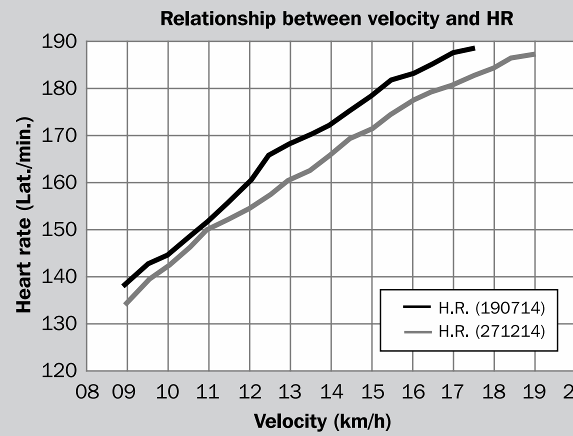
Type of sport	Men (ml/kg/min)	Women (ml/kg/min)
Endurance sports		
Athletics (long distance)	75-80	65-70
Nordic Ski	75-78	65-70
Duathlon	75-78	
Cycling en route	70-75	60-65
Athletics (medium distance)	70-75	65-68
Ice skating	65-72	55-60
Orientation races	65-72	60-65
Swimming	60-70	55-60
Rowing	65-69	60-64
Track cycling	65-70	55-60
Canoeing	60-68	50-55
Athletic walking	60-65	55-60
Games		
Football	50-57	
Handball	55-60	48-52
Ice Hockey	55-60	
Volleyball	55-60	48-52
Basketball	50-55	40-45
Tennis	48-52	40-45
Table tennis	40-45	38-42
Fighting sports		
Boxing	60-65	
Fight	60-65	
Judo	55-60	50-55
Fencing	45-50	40-45
Power Sports		
Speed cycling (200 track)	55-60	45-50
Athletics speed (100-200)	48-52	43-47
Long jump	50-55	45-50
Combined tests (hepta-decathlon)	60-65	50-55
Weightlifting	40-50	
Weight and disc throwing	40-45	35-40
Javelin	45-50	42-47
Pole vault	45-50	
Ski jumps	40-45	
Technical-acrobatic sports		
Alpine Ski	60-65	48-53
Figure skating	50-55	45-50
Gymnastics	45-50	40-45
Rhythmic gymnastics		40-45
Sailing	50-55	45-50
Shooting	40-45	35-40

Table 30. Exercise intensity based on HR and its relation to the percentage of maximal VO_2.

% VO_2max	% base HR	% HRmax
90	90	98
80	80	89
70	70	82
60	60	76
50	50	69
40	40	63

Adapted from Swain *et al.*[307].

Figure 21. Comparison of two stress tests after 5 months of training.



VEL. (km/k)	RITMO/ Km	F.C. (190714)	F.C. (271214)	% F.C. Máx.
09.0	6:40	138	**134**	70.9%
09.5	6:19	142	**139**	73.5%
10.0	6:00	144	**142**	75.1%
10.5	5:43	148	**146**	77.2%
11.0	5:27	151	**150**	79.4%
11.5	5:13	155	**152**	80.4%
12.0	5:00	160	**154**	81.5%
12.5	4:48	165	**157**	83.1%
13.0	4:37	168	**160**	84.7%
13.5	4:27	170	**162**	85.7%
14.0	4:17	172	**165**	87.3%
14.5	4:08	175	**169**	89.4%
15.0	4:00	178	**171**	90.5%
15.5	3:52	181	**174**	92.1%
16.0	3:45	183	**177**	93.7%
16.5	3:38	185	**179**	94.7%
17.0	3:32	187	**180**	95.2%
17.5	3:26	188	**182**	96.3%
18.0	3:20		**184**	97.4%
18.5	3:15		**186**	98.4%
19.0	3:09		**187**	98.9%

athlete has been able to complete three more loads of the ST, and that the HR is lower in each load, especially from 80% of the HRmax.

When the ST is performed with lactate control, it provides greater precision in the evaluation of the effects of training, as shown in Figure 22. In the first two graphs we see a shift to the right of the lactate curve and the intensity of training, indicating an improvement in shape. The effect is more pronounced in the first one, in the high loads, with little change in the more aerobic loads, which demonstrates a greater training

Table 31. Functional training areas from the data of VAM, AT and HR max.

Kind of work	% VAM	%AT*	% HR max	%HRR	Lactate, mmol/l**	Type of training
Aerobic condition I (capacity)	60-80	70,5-94,1	75-88	60-80	1-3	
A	60-70	70,5-82,3	75-82	60-70	1,0-1,6	V0 (regenerative running)
B	70-75	82,3-88,2	82-85	70-75	1,6-2,3	$V1_1$ (running or slow run)
C	75-80	88,2-94,1	85-88	75-80	2,3-3,0	$V1_2$ (running or medium run)
Aerobic condition II power)	80-99	94,1-116,5	88-100	80-99	3-6	
A	80-85	94,1-100,0	88-91	80-85	3,0-4,0	$V1_3$ (running or fast running)
B	86-94	101,0-110,5	92-97	86-94	4,0-5,0	Long extensive intervals
C	95-99	110,5-116,5	98-100	95-99	5,0-6,0	Short extensive intervals
VAM	100-115	117,5-135,3			8-12	
A	100-103	117,5-121,2			8,0-9,0	Long intensive intervals (1.000-800)
B	104-108	122,2-127,0			9,0-10,5	Medium intensive intervals (600-400)
C	108-115	127,0-135,3			10,5-12	Short intensive intervals (200-100)
Anaerobic condition I (capacity)	105-125	123,5-147,0			12-16	
A	105-112	123,5-131,8			12-14	Long extensive repetitions (1.00-500)
B	113-125	133,0-147,0			14-16	Short extensive repetitions (500-100)
Anaerobic condition II (power)	126-138	148,2-162,3			>16	Intensive repetitions (300-100)

*Supposing AT at VAM 85%
*Supossing AT at lactate = 4mmol.

Figure 22. Different evolutions of the lactate curve after a training process[149].

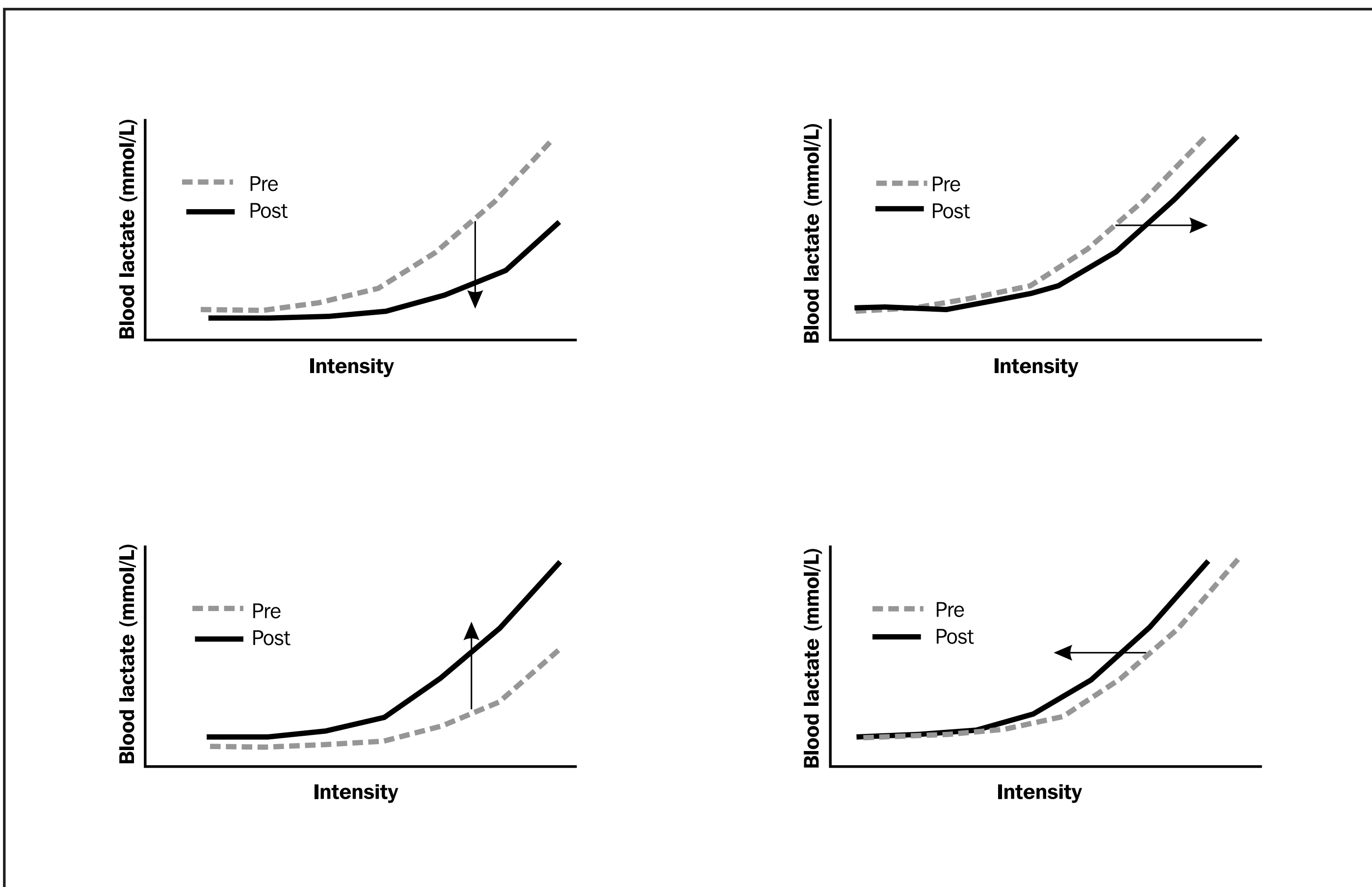


Table 32. VAM intensities that can be maintained at different distances.

Distance	Intensity
100 meters	150.0-180.0%
200 meters	150.0-180.0%
400 meters	125.0-135.0%
800 meters	116.0-122.0%
1.500 meters	106.0-112.0%
1.609 meters (mile)	105.0-111.0%
3.000 meters	97.0-103.0%
3.000 m. obstacles	90.0- 94.0%
5.000 meters	94.0-98.0%
10.000 meters	88.0-93.0%
20.000 meters	85.0-90.0%
21.097 meters	84.5-89.5%
42.195 meters	75.0-82.0%
100.000 meters	57.0-60.0%

Modified from Peronnet and Thibault[309] and Leger Mercier and Gauvin[312].

Table 33. Classification of the level of cardiorespiratory condition according to MET*.

	MET	VO_2max (ml/kg/min)
Very low	1-3.9	3.5-13.9
Low	4-6.9	14-24.9
Medium	7-10.9	25-38.9
Good	11-13.9	39-48.9
High	14-16	49-56
Very high	>16	>56

*Data for 40 years old adults. In women, 10-20% less.

in intensities above its threshold. In the last two graphs a worsening of the state of shape evidenced by the displacement of the curve to the left is verified.

Stress test in other situations

Exercise prescription

Exercise prescription is defined as the process by which a person is recommended to have a physical activity regimen in a systematic and individualized way. The main aims of physical exercise prescription include improving physical fitness, improving health (health promotion, prevention and treatment of diseases) and improving safety in the practice of physical exercise[315].

Physical fitness is defined as the ability to perform the usual activities of daily life without fatigue and so that active leisure activities can be enjoyed and deal with emergencies without excessive fatigue. An adequate physical fitness helps to prevent diseases caused by inactivity[316].

The most important components of fitness are strength and strength-endurance, flexibility, an adequate body composition, balance, coordination and cardiorespiratory endurance. The latter is probably the most important component, along with strength, from the point of view of health, and which will be referred to in this section, as it can be assessed with an ST[317].

The results obtained in the ST are basic for physical exercise prescription in an individualized way: for the improvement on sports performance, for the indication of physical exercise in the improvement of the physical fitness in the general population, and for the prevention and treatment of a large number of diseases.

Exercise prescription in competitive sport

Although the concept of "exercise prescription" is not used in competitive sport, the improvement of the aerobic profile wanted in many sports will be based on the diagnosis or objectification of aerobic power (VO_2max) and aerobic-anaerobic transition: Thresholds 1 and 2, either ventilatory (VT1 / VT2) or lactate (LT1 / LT2), at the time of study and in the control evaluations throughout the season or sports seasons.

Data at maximum level and in the aerobic-anaerobic transition obtained in the medical tests (metabolic, physical workload, cardiovascular, respiratory) will be used to plan the loads and the trainings by the physical trainers of each sport specialty[317].

Prescription of exercise in healthy sport

The usual practice of physical activity and exercise reduces total morbidity and mortality. Current scientific evidence shows clear health benefits for CVD (ischemic heart disease, cerebrovascular disease, HBP), metabolic diseases (type 2 diabetes, metabolic syndrome, overweight-obesity), certain types of cancers (colon cancer and breast cancer), muscle-skeletal system (strength improvement, osteoporosis), functional dependence in geriatrics and improvement of cognitive function, as well as in anxiety and depression[318-322].

Healthy physical exercise should have certain characteristics, both in the type of activity and in the frequency, duration, intensity and progression, and must be oriented to the improvement of some of the qualities of the physical fitness that are related to health, especially with cardiorespiratory endurance.

The exercise prescription will be based on its individualization, that is, adapting the prescription as much as possible to the characteristics of each patient[322-325].

In the prescription of physical exercise, the frequency and the duration follow a generally accepted standards, but it must taken into account the physiological individualization of the retraining program (intensity).

The results obtained in an ergometry (cardiovascular: HRmax, BP, mechanical performance: achieved load, metabolic: VO_2max, ventilatory thresholds, lactate values, dyspnea threshold, visual analogue scale of effort perception) can be the base and large usefulness in the correct prescription of physical exercise in an individualized way[326].

In addition to the physiological vision, it is also necessary to individualize the prescription taking into account personal and family medical history, associated pathologies presented by patients, medical treatments that are following, socio-cultural and economic level, and personal goals and preferences.

Exercise prescription: aerobic power and capacity. Aerobic endurance

Maximum aerobic power (VO_2max) is understood as the maximum individual capacity to resynthesize ATP by the oxidative metabolic pathway.

Endurance capacity (also called cardiorespiratory resistance) is the physical and psychic ability to bear fatigue during relatively long efforts, and also the ability to get recovered quickly after completion. This physiological quality is related to the improvement and optimization of the capacity to produce energy (ATP) by the oxidative pathway, without overstimulation of extramitochondrial glycolysis[130].

In sport for health purposes, it is important to highlight the retraining of aerobic endurance, which is a quality that reflects the functional capacity of circulatory and respiratory systems to get adapted to the needs of muscle metabolism during exercise and recovery[316].

Cardiorespiratory endurance is one of the physiological qualities that are directly related to the improvement of health and quality of life[326]. The characteristics of the exercise that allows the development of this quality in terms of type of activity, frequency, duration, intensity and other aspects for its realization are described now.

Types of activity

The exercise for the development of aerobic/cardio-respiratory endurance is performed by activities that mobilize large muscle groups, in an aerobic way and that can be maintained for prolonged periods of time. They may be classified according to: 1) the energy expenditure they require, 2) the possibility of maintaining a more or less constant energy expenditure during their realization, and 3) the impact they have on the joints.

In order to the practice of healthy sport, activities that require a low-moderate energy expenditure that can be maintained in a constant way and with a medium-low articular impact (even low in certain patients) are realized initially. Examples of these activities are walking, jogging, stationary or walking bicycle, elliptical, swimming and skating, among others[316,322].

Frequency

Training frequencies of between 3 and 5 days per week are recommended. Frequencies of two or fewer days per week sessions do not appear to have significant effects on health-related physiological variables, while frequencies of more than 5 days per week may increase the incidence of injuries on the musculoskeletal system[316,322].

Duration

The duration of each session would be between 30 and 60 minutes, which can be carried out continuously or discontinuously, in series of at least 10 minutes. We should add the recommendation to accumulate (during the development of daily life) between 30 and 60 minutes of daily walking in series of 10 minutes, with the aim to increase caloric expenditure[316,322].

Intensity

It is the most important variable and the most difficult to determine. It can be defined as the degree of effort required by a physical exercise. The main indicators of exercise intensity are physical workload (W), HR and energy expenditure or oxygen consumption (VO_2 or MET).

The MET is a way of expressing the energy consumption of the activity performed and is defined as the amount of oxygen required for maintenance for one minute of the body's metabolic functions with the person at rest and sitting position. One MET corresponds to 3.5 ml / kg / min of VO_2 or 1 kcal / kg / h[130].

Activities of low intensity are considered below 3.5 MET; Activities of moderate intensity, those which require an energy expenditure of between 4 and 8 MET; medium intensity, those from 8 to 12 MET; and high intensity are those higher than 12 MET[315].

METs can also be used to classify the level of cardiorespiratory fitness of people[315] (Table 33).

Due to the simplicity of its control, the physical exercise prescription is usually done through the control of HR.

Use of exercise tests for exercise prescription

As in the diagnostic field and in the control of training, direct and indirect ST can be used to prescribe exercise.

Direct tests

These tests allow the measurement of VO_2max, maximal W and HRmax, as well as VO_2 (% of VO_2max), workload and HR in the aerobic-anaerobic transition (VT1 / LT1 and VT2 / LT2 thresholds). These data will be used for the prescription of physical exercise.

In the continuous exercise prescription for healthy sport and for treatment of chronic diseases, the recommended intensities are below VT2, usually in VT1, although the training can also be done in an intervallic way, according to the intensities corresponding to VT1, with durations of 4 minutes peaks of 1 minute in the intensities of VT2 or slightly below this intensity[323,327].

Indirect tests

The prescription of exercise by indirect ST is fundamentally based on the HRR because of its linear relation 1/1 with the energy expenditure (VO_2max / Reserve VO_2). Thus, a physical exercise intensity of 60% of the HRR will correspond to 60% of the VO_2max[327].

The HRR is defined as the difference between HRmax reached in ergometry minus resting or baseline HR. The reserve VO_2 is defined as the difference between the VO_2max reached in ergometry and the resting VO_2.

The training HR (Karvonen formula) is equal to the resting HR plus the percentage (training intensity) that is indicated or prescribed, HRR[328].

The percentage of training HR is, as a general rule, between 40% and 85% of the HRR, according to the goals and the situation of the patient or the disease.

Typically, the training intensity, in chronic pathologies, will be 40% to 60% of the HRR.

Karvonen Formula:

HRR=HRmax – Resting HR

Training HR = [(HRmax – Resting HR) x %workload] + Resting HR

The percentage of workload in healthy people is between 40% and 85% of the HRR, and in cases of chronic pathologies it is usually between 40% and 60% of the HRR.

Another method of exertion intensity control, which is useful in exercise prescription, is the subjective assessment of exertion through the rating of perceived exertion (RPE) or Borg scale[76]. The values of the original scale ranged from 6 to 20 and increased linearly with exercise intensity, correlating with the physiological variables studied: HR, VO_2, lactate, W, ventilation, etc. The new scale, from 0 to 10, also adapts to the modifications that occur during the realization of PE.

Moderate exercise intensities (40-60% of the HRR) correspond to a score of 12-13 or 5-6 on the Borg scales, while vigorous intensities (60-84% of the HRR) correspond to scores of 14-16 or 7-8.

Usually, in patients with chronic diseases, the exercise program starts with moderate intensities, 40-60% of the HRR, or even less depending on the pathology, the degree of sedentarism and the possibilities of the person. Subsequently, the intensity and volume of the physical exercise will be increased according to the adaptation to the effort and the goals set for each patient, until a maximum of 75% of the HRC is reached.

Progression

At the beginning of the exercise programs, intensities, durations and low frequencies will be used, increasing them progressively and adapting them individually to the situation of each patient.

These programs are generally divided into the initiation, improvement and maintenance phases. In the latter, the most important is the maintenance of intensity.

As a general rule, realistic goals should be set, with a very soft start, avoiding fatigue, as well as the pain and discomfort of the patient. It is necessary to try that the patient is comfortable with the accomplishment of the prescribed activity.

Once the planned objectives are reached, new ones will be reviewed and proposed, incorporating regular exercise as a daily habit in the patient's life and remembering that, in order to maintain the positive effects of exercise for health, this should be practiced regularly during all lifelong.

Adherence

One of the biggest problems associated with physical exercise prescription is the high dropout rate. Therefore, it is so important to use techniques and strategies to achieve adherence of patients and the general population to exercise programs.

In this sense, the motivation of the patient is essential. Several studies[329-331] show a greater adherence to exercise programs when they are simple and easy to perform and to incorporate into the patients' normal lives.

Other strategies, such as frequent consultations to check the realization of the exercise program, the achievement of objectives, and positive reinforcement are useful in improving adherence to exercise programs. Finally, it seems that periodic physical tests (ST, 6-minute walk test and anthropometric studies) also improve adherence to exercise programs[332,333].

Structure of a training session

The training session, classically, consists of three parts:

- Warming up, 5-10 minutes of duration.
- The effort or training itself, with the type, intensity and duration indicated.
- The recovery, in which progressively decreases the exercise until the return to calm.

Do not forget to include exercises in strength, flexibility and balance.

Risks of exercise

The practice of exercise involves an increased risk of injuries to the musculoskeletal system, an increase in cardiovascular risk and, to a lesser extent, the presence of medical problems related to the control of internal temperature[322].

The injuries of the musculoskeletal system should be avoided or minimized, so that they must not be an excuse for sedentarism for patients. As for cardiovascular risk, the most important complications are sudden death and myocardial infarction.

Prescription of exercise in chronic diseases

Prescribing recommendations are summarized below for some of the most prevalent chronic diseases or conditions[3,334-336].

Obesity

- *Aerobic exercise:* 60% of the HRR / VO_2max, 60 minutes daily continuous or in series, most of the days of the week.
- *Strength:* 2 days per week, big muscle groups of upper and lower train, and abs. Two or three sets of 8-15 repetitions per session. Intensity: 30-60% of repetition maximum (RM).
- *Objective:* increase in caloric expenditure, increase of lipolysis, decrease in total and visceral fat mass, and maintenance or improvement of lean weight.

Dyslipidemia

- *Aerobic exercise:* 60% of the HRR / VO_2max, 60 minutes daily continuous or in series, most of the days of the week. The improvement is dependent on the dose, mainly the volume and not the intensity.
- *Strength:* There is no evidence of beneficial effects of this exercise on dyslipidemia.

– *Objective:* to improve the lipid profile, which is independent of weight loss, by an enzymatic improvement of the lipid metabolism.

Type 2 diabetes

– *Daily exercise, aerobic exercise and strength* (recommendations already described for obesity), with individualized intensities, starting with 40-60% of the HRR / VO_2max and increasing according to the adaptation to the training with a duration of 60 minutes per session.
– *Objective:* to improve glucose metabolism, increase insulin sensitivity and improve postprandial blood glucose control, among others.

Arterial hypertension

– *Aerobic exercise*: intensity based on the response of the BP to the effort, most of the days, 60 minutes per session.
– *Strength:* dynamic and isometric.
– *Objective:* prevention of the development of hypertension and decrease of BP by reduction of peripheral vascular resistance and sympathetic tone, and of circulating catecholamines, among other mechanisms involved.

Assessment of therapeutic response

According to Task Force about ST, published in the United States and ACSM[249,337], ST with respiratory gases measure is the best available test for estimating functional capacity, for assessing response to interventions that may affect exercise capacity, to evaluate the evolution of diseases that may limit exercise capacity, and to help to distinguish the limitations of effort capacity of cardiac or pulmonary origin.

The therapeutic response to the prescribed exercise can be evaluated by a ST in which changes in the metabolic parameters (VO_2max, RQ, ECG, HR, BP) are quantified[3].

Evaluation of the therapeutic response in arterial hypertension

A ST is useful to improve the prescription of exercise in patients with AHT and to assess the efficacy of an antihypertensive treatment[338].

There are no protocols on exercise prescription in hypertension based on ST results, same happens with other methods such as ambulatory monitoring. However, there are studies in which effort response has been used as a method to assess the efficacy of antihypertensive drugs[338-341].

Assessment of the therapeutic response in obesity

ST is useful in assessing the therapeutic response in obese patients, since it can be aimed the improvement in the oxidation of substrates (fats and carbohydrates), functional capacity and cardiovascular response[342,343].

Evaluation of therapeutic response in diabetes

Similarly to the obese patient, with ST in diabetic patients, metabolic, cardiovascular and functional improvement can be evaluated[344].

It should be taken into account that a poor recovery of post-exertional HR has been associated with adverse cardiovascular events in the diabetic population[291].

Evaluation of therapeutic response in peripheral arterial disease

ST is the most objective test for the clinical evaluation of the therapeutic response in patients with peripheral arterial disease, due to the precision in the quantification of exercise capacity and in determining the time walking until the appearance of symptoms[345,346]. In addition, it can be associated with the measurement of arm-ankle BP indexes after exercise[346]. The response to the stress test is, in these patients, a good prognostic indicator[347].

Evaluation of the therapeutic response in dyslipidemias

In patients with dyslipidemia, ST assesses the metabolic response to the prescribed exercise; If the therapeutic response is correct, a greater oxidation of the lipids will be observed[343,348-350].

The stress test report

Many of the values obtained in the ST are useful in the clinical sports context, but it is very important to express in a report the large amount of data obtained in the ST so that they can be used in a practical way. Therefore, the content of the final report of the ST will depend on the indication for which it was made.

The report should include the reason for the test and the type of test, the anthropometric data of the patient, the main clinical data and the physiological responses to the exercise performed: duration, workload, symptoms, ending reason, VO_2max, RQ, VE, VE/VCO_2, VE/VO_2, BP, lactate concentration and electrocardiographic parameters (HR, ST-T modifications, arrhythmias, etc.)[337].

It should be concluded with some concise and specific comments or recommendations that respond to the reasons for the test.

When it comes to competitive athletes, the report should indicate the value of VO_2max, or aerobic power, and aerobic-anaerobic transition: thresholds 1 and 2, whether ventilatory (VT1/ VT2) or lactate (LT1/LT2); Also the workloads and HRs in each load, as well as their evolution, if previous data are available[317]. In certain sports, the zone of maximum fat oxidation should be included in the report[351].

When a ST is performed for the prescription of exercise for health improvement purposes, the cardiovascular parameters (submaximal and maximum HR, PBP), mechanical performance (load achieved), metabolic parameters (VO_2max, ventilatory thresholds or lactate), the dyspnea threshold and the Rate of perceived exertion[76]. All can be very useful in the correct prescription of physical exercise in an individualized way[3,346].

The ST report for exercise prescription should include the recommended types of activity and their frequency, duration and intensity[316,322], indicating whether they are recommended in workload or rate of perceived exertion (RPE), or both, and also HR or energy expenditure (VO_2 or MET) recommended[130,336]. Depending on the pathology, the metabolic zones in which more fats or more carbohydrates are oxidized must be reported[352,353], and in certain conditions, such as obesity and dyslipidemias, the zone of maximum oxidation of fats[343].

ABBREVIATIONS

ABPM: Ambulatory blood pressure monitoring
ACC: American College of Cardiology
ACSM: American College of Sports Medicine
ADP: Adenosine diphosphate
AF: Atrial fibrillation
AHA: American Heart Association
AHT: Arterial hypertension
AT: Anaerobic Threshold
ATP: Adenosine triphosphate
AVB: Atrioventricular block
BF: Respiratory rate
BHR: Baseline Heart Rate
BMI: Body mass index
BP: Blood pressure
bpm: beats per minute
BR: Breathing rate
Cal: Calories
CO_2: Carbon dioxide
COPD: Chronic obstructive pulmonary disease
CPR: Cardiopulmonary resuscitation
CrP: Creatine Phosphate
CVA: Cerebrovascular accident
CVD: Cardiovascular disease
DBP: Diastolic Blood Pressure
ECG: Electrocardiogram
EMHR: Estimated maximum heart rate
ESH: European Society of Hypertension
FCR: Heart rate reserve
F_ECO_2: Fraction of carbon dioxide in exhaled air
F_EO_2: Fraction of oxygen in expired air
FEV1: Maximum volume exhaled in the first second of a forced breath
h: Hour
HR: Heart rate
HR: Heart rate
HRmax: Maximum heart rate
IL-6: Interleukin 6
J: Joules
Kcal: Kilocalories
KJ: Kilojoules
Km: kilometers
Kpm: Kilopondmeter
l: Liter
LBBB: Left bundle branch block
m: Meter
MAOD: Test of maximal accumulated oxygen deficit
MAV: Maximum aerobic velocity
MET: Metabolic Equivalent
mg: Milligrams
MI: Myocardial infarction
min: Minutes
ml: milliliters
mm: Millimeters
mmHg: Millimeters of mercury
mmol: Millimoles
MRI: Magnetic resonance imaging
ms: Milliseconds
mV: Millivolts
O_2: Oxygen
OCPE: Oxygen consumption post-exercise excess
$PaCO_2$: Partial carbon dioxide pressure in arterial blood
PaO_2: Partial oxygen pressure in arterial blood
$P_{ET}CO_2$: Partial pressure of carbon dioxide at the end of respiration
$P_{ET}O_2$: Partial oxygen pressure at the end of expiration
PMA: Maximum power attained
PWC: Physical work capacity
RBBB: Right bundle branch block
RER: Respiratory exchange ratio, VCO2 / VO2
RM: Maximum repetition
RPE: Rating of perceived exertion
rpm: Revolutions per minute
RQ: Respiratory Ratio
s: Seconds
SaO_2: Arterial oxygen saturation
SBP: Systolic blood pressure
SM: Sports Medicine
SMBP: Self-measurement of blood pressure
SPECT: Single Photon Emission Computed Tomography
ST: Stress test
TMHR: Theoretical maximum heart rate
TRIMP: Training impulse
Tv: tidal or current volume
VCO_2: Production of carbon dioxide
Vd: Dead Space
VE: Ventilation
VF: Ventricular fibrillation
VO_2: Oxygen consumption
VO_2max: Maximum oxygen consumption
W: Watts
WPW: Wolff-Parkinson-White Syndrome

Bibliography

1. Arós F, Boraita A, Alegría E, Alonso AM, Bardají A, Lamiel R, *et al.* Guías de práctica clínica de la Sociedad Española de Cardiología en pruebas de esfuerzo. *Rev Esp Cardiol* 2000;53:1063-94.
2. Balady GJ, Arena R, Sietsema K, Myers J, Coke L, Fletcher GF, Forman D, Franklin B, Guazzi M, Gulati M, Keteyian SJ, Lavie CJ, Macko R, Mancini D, Milani RV; American Heart Association Exercise, Cardiac Rehabilitation, and Prevention Committee of the Council on Clinical Cardiology; Council on Epidemiology and Prevention; Council on Peripheral Vascular Disease; Interdisciplinary Council on Quality of Care and Outcomes Research. Clinician's Guide to cardiopulmonary exercise testing in adults: a scientific statement from the American Heart Association. *Circulation.* 2010;122:191-225.
3. Fletcher GF, Ades PA, Kligfield P, Arena R, Balady GJ, Bittner VA, *et al;* American Heart Association Exercise, Cardiac Rehabilitation, and Prevention Committee of the Council on Clinical Cardiology, Council on Nutrition, Physical Activity and Metabolism, Council on Cardiovascular and Stroke Nursing, and Council on Epidemiology and Prevention. Exercise standards for testing and training: a scientific statement from the American Heart Association. *Circulation* 2013;128:873-934.
4. Strath SJ, Kaminsky LA, Ainsworth BE, Ekelund U, Freedson PS, Gary RA, *et al.* Guide to the assessment of physical activity: Clinical and research applications: A Scientific Statement from the American Heart Association. *Circulation.* 2013;128:2259-79.
5. Myers J, Arena R, Franklin B, Pina I, Kraus WE, McInnis K, *et al.* Recommendations for clinical exercise laboratories. A Scientific Statement from the American Heart Association. *Circulation.* 2009;119:3144-61.
6. Gibbons RJ, Balady GJ, Bricker JT, Chaitman BR, Fletcher GF, Froelicher VF, *et al;* American College of Cardiology/American Heart Association Task Force on Practice Guidelines. Committee to Update the 1997 Exercise Testing Guidelines. ACC/AHA 2002 guideline update for exercise testing: summary article. A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Update the 1997 Exercise Testing Guidelines). *J Am Coll Cardiol.* 2002;40:1531-40.
7. Fletcher GF, Balady GJ, Amsterdam EA, Chaitman B, Eckel R, Fleg J, *et al.* Exercise standards for testing and training: a statement for healthcare professionals from the American Heart Association. *Circulation*. 2001;104:1694-740.
8. American College of Sports Medicine Position Stand and American Heart Association. Recommendations for cardiovascular screening, staffing, and emergency policies at health/fitness facilities. *Med Sci Sports Exerc* .1998;30:1009-18.
9. American College of Sports Medicine; American Heart Association. American College of Sports Medicine and American Heart Association joint position statement: automated external defibrillators in health/fitness facilities. *Med Sci Sports Exerc*. 2002;34:561-4.
10. Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Rep.* 1985;100:126-31.
11. Lamb DR, Fisiología del esfuerzo. *Respuestas y adaptaciones*. Nueva York: Ed. Augusto E. Pila Teleña, 1978;18-9.
12. Wilmore JH, Costill DL. Eds. *Fisiología del esfuerzo y del deporte*. Barcelona: Paidotribo. 2007;34-61.
13. McArdle W, Katch F, Katch V. E*xercise Physiology: nutrition, energy and human performance.* Baltimore: Lippincott Williams & Wilkins, 2007.
14. Rabadán M. Test de campo. En: Segovia JC, López-Silvarrey FJ, Legido JC, eds. *Manual de valoración funcional.* Madrid: Elsevier, 2008;293-305.
15. López J, Fernández A. *Fisiología del Ejercicio.* Madrid: Panamericana, 1995;7-8.
16. Peinado B, Calvo PJ, Bruzos SC, Gómez Candel C, Iglesias Rosado C. *Alimentación y nutrición en la vida activa: ejercicio físico y deporte.* Madrid: UNED, 2014.
17. Gibbons RJ. Abnormal heart-rate recovery after exercise. *Lancet*. 2002;359:1536-7.
18. Halliwill JR, Sieck DC, Romero SA, Buck TM, Ely MR. Blood pressure regulation X: what happens when the muscle pump is lost? Post-exercise hypotension and syncope. *Eur J Appl Physiol.* 2014;114:561-78.
19. Sarnoff SJ. Hemodinamic determinants of oxygen consumption of the heart with special reference to the tensión-time index. En: Rosenbaum FF, Hoeber PB, eds. *Work and the heart*. New York: Harper & Bros, 1959.
20. American College of Sports Medicine. *ACMS's resource manual for guidelines for exercise testing and prescription*. 7nd. ed. Philadelphia: Wolters Kluwer - Lippincott Williamns & Wilkins, 2014;57.
21. Astrand PO, Rodahl K, Dahl HA, Stromme SB. *Manual de Fisiología del ejercicio*. Barcelona: Paidotribo, 2010.
22. Santalla E. Factores determinantes del ejercicio físico. En: Naranjo Orellana J, Santalla Hernández A, Manonelles Marqueta P, eds. *Valoración del rendimiento del deportista en el laboratorio.* Barcelona: Esmon Publicidad, 2013;61-87.
23. Lopez Chicharro J, Legido Arce J. *Umbral aerobio.* Madrid: Interamericana - McGraw Hill, 1991;1-23.
24. Ley Orgánica 15/1999, de 13 de diciembre, de Protección de Datos de Carácter Personal. BOE, número 298, 14 de diciembre 1999. Páginas 43088-43099.
25. Sosa Rodriguez V. Las pruebas de esfuerzo y de estimulación. Instituto Nacional de Medicina y Seguridad del Trabajo. Estudio de la incapacidad laboral por enfermedades cardiocirculatorias. Instituto Nacional de Medicina y Seguridad del Trabajo. Madrid, 1998;37-53.
26. Gil S. Prueba de Esfuerzo. *NEUMOSUR.* 1997;9:40-8.
27. De Teresa C. Protocolos de ergometría para uso clínico en deportistas. En: Naranjo Orellana J, Santalla Hernández A, Manonelles Marqueta P, eds. *Valoración del rendimiento del deportista en el laboratorio.* Barcelona: Esmon Publicidad, 2013;427-59.
28. Lear SA, Brozic A, Myers JN, Ignaszewski A. Exercise stress testing. An overview of current guidelines. *Sports Med* 1999;27:285-312.
29. Myers J, Voodi L, Umann T, Froelicher VF. A survey of exercise testing: methods, utilization, interpretation, and safety in the VAHCS. *J Cardiopulm Rehabil* 2000;20:251-8.
30. Ley 44/2003, de 21 de noviembre, de ordenación de las profesiones sanitarias. BOE núm. 280. Sábado 22 noviembre 2003. 41442- 41458.
31. Schlant RC, Friesinger GC, Leonard JJ. Clinical competence in exercise testing. A statement for physicians from the ACP/ACC/AHA Task Force on Clinical Privileges in Cardiology. *J Am Coll Cardiol* 1990;16:1061-5.
32. Kligfield P, Gettes LS, Bailey JJ, Childers R, Deal BJ, Hancock EW, *et al;* American Heart Association Electrocardiography and Arrhythmias Committee, Council on Clinical Cardiology; American College of Cardiology Foundation; Heart Rhythm Society, Josephson M, Mason JW, Okin P, Surawicz B, Wellens H. Recommendations for the standardization and interpretation of the electrocardiogram: part I: The electrocardiogram and its technology: a scientific statement from the American Heart Association Electrocardiography and Arrhythmias Committee, Council on Clinical Cardiology; the American College of Cardiology Foundation; and the Heart Rhythm Society: endorsed by the International Society for Computerized Electrocardiology. *Circulation*. 2007;115:1306-24.
33. Perloff D, Grim C, Flack J, Frohlich ED, Hill M, McDonald M, Morgenstern BZ. Human blood pressure determination by sphygmomanometry. *Circulation.* 1993;88(pt 1):2460-70.
34. Hopkins SR. Exercise induced arterial hypoxemia: the role of ventilation-perfusion inequality and pulmonary diffusion limitation. *Adv Exp Med Biol.* 2006;588:17-30.
35. Naranjo J. El laboratorio de Fisiología del Ejercicio. Instrumentación. Protocolos de pruebas de esfuerzo. En: Naranjo Orellana J, Santalla Hernández A, Manonelles Marqueta P, eds. *Valoración del rendimiento del deportista en el laboratorio.* Barcelona: Esmon Publicidad, 2013;37-60.
36. Villarino-Cabezas S, González-Ravé JM, Juárez D, Navarro F. Comparison between a laboratory test in kayak-ergometer and continuous and interval exercises on open water in well-trained young kayakers. *ISMJ*. 2013;14:196-204.
37. Alacid F, Torres G, Sanchez J, Carrasco L. Validez de la ergometría en piragüismo para la determinación del umbral anaeróbico. Estudio preliminar. Seminario del III Congreso de la Asociación Española de Ciencias del Deporte. Valencia. 2004.
38. Holway F, Guerci G. Capacidad predictiva de los parámetros antropométricos y de maduración sobre el rendimiento de adolescentes noveles en remo-ergómetro. *Apunts Med Esport.* 2012;47:99-104.
39. Rabadán M, Boraita A. Las pruebas de esfuerzo en la valoración cardiológica y funcional del deporista. En: Manonelles P, Boraita A, Luego E, Boraita A, eds. *Cardiología del Deporte*. Barcelona: Nexus Médica, 2005;79-123.
40. Villa JG. *Valoración del metabolismo aeróbico en el laboratorio.* Monografia FEMEDE nº6. Pamplona: FEMEDE, 1999;345-425.
41. American College of Sports Medicine. ACSM's *Guidelines for graded Exercise testing and prescription*. Ninth edition. Baltimore: Lippincott Williams & Wilkins, 2014.
42. Will PM, Walter JD. Exercise testing: Improving performance with a ramped Bruce protocol. *Am Heart J*. 1999;138:1033-7.
43. Whipp BJ, Davis JA, Torres F, Wasserman K. A test to determine parameters of aerobic function during exercise. *J Appl Physiol*. 1981;50:217-21.
44. Davis JA, Whipp BJ, Lamarra N, Huntsman DJ, Frank MH, Wasserman K. Effect of ramp slope on measurement of aerobic parameters from the ramp exercise test. *Med Sci Sports Exerc.* 1982;14:339-43.
45. Myers J, Buchanan N, Walsh D, Kraemer M, McAuley P, Hamilton-Wessler M, Froelicher VF. Comparison of the ramp versus standard exercise protocols. *J Am Coll Cardiol* 1991;17:1334-42.
46. Margaria R, Aghemo P, Rovelli E. Measurement of muscular power (anaerobic) in man. *J Appl Physiol.* 1966;21:1662-4.

47. Astrand I. Aerobic work capacity in men and women with special reference to age. *Acta Physiol Scand;* Suppl 1960;49:1-92.

48. Lambert G. The exercise blood pressure test of myocardial efficiency. *Br Med J.* 1918;2:366-8.

49. Scherf D. Fifteen years of electrocardiographic exercise test in coronary stenosis. *N Y State J Med.* 1947;47:2420-4.

50. Pina IL, Baladi GJ, Hanson P, LabovitzAJ, Madonna DW, Myers J. Guidelines for clinical exercise testing laboratories. A statement for healthcare professionals from Committee on exercise and cardiac rehabilitation, American Heart Association. *Circulation.* 1995;91:912-21.

51. Blais S, Berbari J, Counil FP, Dallaire F. A systematic review of reference values in pediatric cardiopulmonary exercise testing. *Pediatr Cardiol.* 2015;36:1553-64.

52. Rowland TW. Aerobic exercise testing protocols. En: Rowland TW ed. Pediatric laboratory exercise testing. Clinical guidelines. Champaign IL: *Human Kinetics,* 1993;19-41.

53. James FW, Blomqvist CG, Freed MD, Miller WW, Moller JH, Nugent EW, *et al*. Standards for exercise testing in the pediatric age group. American Heart Association Council on Cardiovascular Disease in the Young. Ad hoc committee on exercise testing. *Circulation.* 1982;66:1377A-97A.

54. Strong WB, Stanitski CL, Smith RE, Wilmore JH. Cardiovascular responses to exercise in childhood. *AJDC.* 1990;144:1255-60.

55. Hartung GH, Lally DA, Blancq RJ. Comparison of treadmill exercise testing protocols for wheelchair users. *Eur J Appl Physiol.* 1993;66:362-5.

56. Klasnja A, Barak O, Popadić-Gaćesa J, Drapsin M, Knezević A, Grujić N. Analysis of anaerobic capacity in rowers using Wingate test on cycle and rowing ergometer. *Med Pregl.* 2010;63:620-3.

57. Ozkaya O. Familiarization effects of an elliptical all-out test and the Wingate test based on mechanical power indices. *J Sports Sci Med*. 2013;12:521-5.

58. Cumming GR, Everatt D, Hastman L. Bruce treadmill test in children: normal values in a clinic population. *Am J Cardiol.* 1978;41:69-75.

59. López Chicharro J. Aspectos fisiológicos del ejercicio físico en la edad infantil. En: López Chicharro J, Fernández Vaquero A, eds. *Fisiología del Ejercicio,* 3ª edición. Buenos Aires: Editorial Médica Panamericana, 2006;609-11.

60. Pérez Ruiz M. Pruebas funcionales de valoración aeróbica. En: López Chicharro J, Fernández Vaquero A, eds. *Fisiología del Ejercicio*, 3ª edición. Buenos Aires: Editorial Médica Panamericana, 2006;449.

61. Billat V. Teoría del entrenamiento. En: Billat V, ed. *Fisiología y metodología del entrenamiento, de la teoría a la práctica.* 1ª edición. Barcelona: Ed. Paidotribo, 2002;143.

62. Scherer D, Kaltenbach M. Frequency of life-threatening complications associated with exercise testing (author's translation). *Dtsch Med Wochenschr.* 1979;104:1161-5.

63. Rochmis P, Blacburn H. Exercise test: a survey of procedures, safety and litigation experience in approximately 170.000. *JAMA.* 1971;217:1061-6.

64. Rousseau M, Brasseur L. Criteres d'arret des épreuves d'effort. *Acta Cardiol.* 1972;27:392-406.

65. Sheffield LT. Safety of exercise testing volunteer subject: the lipid research clinics prevalence study experience. *J Cardiac Rehab.* 1982;2:395-400.

66. Simón P. Diez mitos en torno al consentimiento informado. *An Sist Sanit Navar.* 2006;29 (supl 2):29-40.

67. Simón Lorda P, Concheiro Carro L. El consentimiento informado: teoría y práctica (I). *Med Clin (Barc).* 1993;100:659-63.

68. Ad hoc Committee on Medical Ethics, American College of Physicians. American College of Physicians Ethics Manual. *Ann Intern Med.* 1984;101:129-37.

69. Abdulla-El Rubaidi O, El Rubaidi-García O, Galicia-Bulnes JM. Consentimiento informado en neurocirugía. *Neurocirugía*. 2002;4:349-57.

70. Gallego Riestra S, Fernández-García B. El consentimiento informado y la documentación clínica en la Medicina del deporte ante la nueva Ley básica reguladora de la autonomía del paciente. *Arch Med Deporte*. 2003;94:149-60.

71. Ley 41/2002, de 14 de noviembre, básica reguladora de la autonomía del paciente y de derechos y obligaciones en materia de información y documentación clínica. BOE núm. 274; Viernes 15 noviembre 2002;40126-32.

72. Neff MJ. Informed consent: What is it? Who can give it? How do we improve it? *Respir Care.* 2008;53:1337-41.

73. Boraita A, Baño A, Berrazueta JR, Lamiel R, Luengo E, Manonelles P, *et al.* Guías de práctica clínica de la Sociedad Española de Cardiología sobre actividad física en el cardiópata (I). *Arch Med Deporte*. 2001;81:9-31.

74. Boraita A, Baño A, Berrazueta JR, Lamiel R, Luengo E, Manonelles P, *et al.* Guías de práctica clínica de la Sociedad Española de Cardiología sobre actividad física en el cardiópata (II). *Arch Med Deporte*. 2001;82:101-33.

75. Borg G. Perceived exertion as an indicator of somatic stress. *Scand J Rehabil Med.* 1970;2:92-8.

76. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc.* 1982;14:377-81.

77. Grant S, Aitchison T, Henderson E, Christie J, Zare S, McMurray J, *et al.* A comparison of the reproducibility and the sensitivity to change of visual analogue scales, Borg scales, and Likert scales in normal subjects during submaximal exercise. *Chest.* 1999;116:1208-17.

78. Wilson RC, Jones PW. A comparison of the visual analogue scale and modified Borg scale for the measurement of dyspnea during exercise. *Clin Sci*. 1989;76:277-82.

79. Neely G, Ljunggren G, Sylvén C, Borg G. Comparison between the Visual Analogue Scale (VAS) and the Category Ratio Scale (CR-10) for the evaluation of leg exertion. *Int J Sports Med.* 1992;13:133-6.

80. Zamunér AR, Moreno MA, Camargo TM, Graetz JP, Rebelo AC, Tamburús NY, *et al.* Assessment of subjective perceived exertion at the anaerobic threshold with the Borg CR-10 scale. *J Sports Sci Med*. 2011;10:130-6.

81. Noble BJ. Clinical applications of perceived exertion. *Med Sci Sports Exerc.* 1982;14:406-11.

82. Chase P, Arena R, Myers J, Abella J, Peberdy MA, Guazzi M, *et al.* Prognostic usefulness of dyspnea versus fatigue as reason for exercise test termination in patients with heart failure. *Am J Cardiol*. 2008;102:879-82.

83. Mark DB, Shaw L, Harrell FE Jr, Hlatky MA, Lee KL, Bengtson JR, *et al.* Prognostic value of a treadmill exercise score in outpatients with suspected coronary artery disease. *N Engl J Med.* 1991;325:849-53.

84. Da Rocha EE, Alves VG, da Fonseca RB. Indirect calorimetry: methodology, instruments and clinical application. *Curr Opin Clin Nutr Metab Care.* 2006;9:247-56.

85. Haugen HA, Chan LN, Li F. Indirect calorimetry: a practical guide for clinicians. *Nutr Clin Pract.* 2007;22:377-88.

86. Katch VL, McArdle WD, Katch FI. Energy expenditure during rest and physical activity. En: McArdle WD, Katch FI, Katch VL, eds. *Essentials of exercise physiology.* 4th ed. Baltimore, MD: Lippincott Williams & Wilkins; 2011;237-62.

87. Jetté M, Sidney K, Blümchen G. Metabolic equivalents (METS) in exercise testing, exercise prescription, and evaluation of functional capacity. *Clin Cardiol.* 1990;13:555-65.

88. Arena R, Myers J, Aslam SS, Varughese EB, Peberdy MA. Technical considerations related to the minute ventilation/carbon dioxide output slope in patients with heart failure. *Chest*. 2003;124:720-7.

89. Ingle L, Goode K, Carroll S, Sloan R, Boyes C, Cleland JG, *et al.* Prognostic value of the VE/VCO2 slope calculated from different time intervals in patients with suspected heart failure. *Int J Cardiol*. 2007;118:350-5.

90. Sun XG, Hansen JE, Garatachea N, Storer TW, Wasserman K. Ventilatory efficiency during exercise in healthy subjects. *Am J Respir Crit Care Med*. 2002;166:1443-8.

91. Yasunobu Y, Oudiz RJ, Sun XG, Hansen JE, Wasserman K. End-tidal PCO2 abnormality and exercise limitation in patients with primary pulmonary hypertension. *Chest.* 2005;127:1637-46.

92. Ponikowski P, Chua TP, Piepoli M, Banasiak W, Anker SD, Szelemej R, *et al*. Ventilatory response to exercise correlates with impaired heart rate variability in patients with chronic congestive heart failure. *Am J Cardiol*. 1998;82:338 -44.

93. Holverda S, Bogaard HJ, Groepenhoff H, Postmus PE, Boonstra A, Vonk-Noordegraaf A. Cardiopulmonary exercise test characteristics in patients with chronic obstructive pulmonary disease and associated pulmonary hypertension. *Respiration.* 2008;76:160-7.

94. Rodgers GP, Ayanian JZ, Balady G, Beasley JW, Brown KA, Gervino EV, *et al.* American College of Cardiology/American Heart Association Clinical Competence statement on stress testing: a report of the American College of Cardiology/American Heart Association/American College of Physicians-American Society of Internal Medicine Task Force on Clinical Competence. *J Am Coll Cardiol*. 2000;36:1441-53.

95. Hung MJ, Hu P, Hung MY. Coronary artery spasm: review and update. *Int J Med Sc.* 2014;11:1161-71.

96. Gauer RL. Evaluation of syncope. *Am Fam Physician.* 2011;84:640-50.

97. Laviolette L, Laveneziana P; ERS Research Seminar Faculty. Dyspnea: a multidimensional and multidisciplinary approach. *Eur Respir J.* 2014;43:1750-62.

98. Pinkstaff S, Peberdy MA, Kontos MC, Finucane S, Arena R. Quantifying exertion level during exercise stress testing using percentage of age predicted maximal heart rate, rate pressure product, and perceived exertion. *Mayo Clin Proc.* 2010;85:1095-100.

99. Kubrychtova V, Olson TP, Bailey KR, Thapa P, Allison TG, Johnson BD. Heart rate recovery and prognosis in heart failure patients. *Eur J Appl Physiol*. 2009;105:37-45.

100. Mansur AJ, Nunes RA. Heart rate response and chronotropic incompetence in exercise stress testing of asymptomatic women. *Womens Health (Lond Engl)*. 2010;6:785-7.

101. Minkkinen M, Nieminen T, Verrier RL, Leino J, Lehtimäki T, Viik J, *et al.* Prognostic capacity of a clinically indicated exercise test for cardiovascular mortality is enhanced by

combined analysis of exercise capacity, heart rate recovery and T-wave alternans. *Eur J Prev Cardiol.* 2015;22:1162-70.

102. Pescatello LS, Franklin BA, Fagard R, Farquhar WB, Kelley GA, Ray CA, American College of Sports Medicine. American College of Sports Medicine position stand. Exercise and hypertension. *Med Sci Sport Exerc*. 2004;36:533-53.

103. American College of Sports Medicine. *ACSM's Guidelines for exercise testing and prescription.* 7th ed. Baltimore: Lippincott Willliams & Wilkins, 2006.

104. Tanaka H, Bassett DR Jr, Turner MJ. Exaggerated blood pressure response to maximal exercise in endurance-trained individuals. *Am J Hypertens.* 1996;9:1099-103.

105. Laukkanen JA, Kurl S, Rauramaa R, Lakka TA, Venalainen JM, Salonen JT. Systolic blood pressure response to exercise testing is related to the risk of acute myocardial infarction in middle-aged men. *Eur J Cardiovasc Prev Rehabil.* 2006;13:421-8.

106. O'Neal WT, Qureshi WT, Blaha MJ, Keteyian SJ, Brawner CA, Al-Mallah MH. Systolic blood pressure response during exercise stress testing: The Henry Ford Exercise Testing (FIT) Project. *J Am Heart Assoc*. 2015;4(5). pii: e002050.

107. Akutsu Y, Shinozuka A, Nishimura H, Li HL, Huang TY, Yamanaka H, *et al.* Significance of ST-segment morphology noted on electrocardiography during the recovery phase after exercise in patients with ischemic heart disease as analyzed with simultaneous dual-isotope single photon emission tomography. *Am Heart J.* 2002;144:335-42.

108. Ranadive SM, Fahs CA, Yan H, Rossow LM, Agiovlasitis S, Agliovlastis S, *et al.* Heart rate recovery following maximal arm and leg ergometry. *Clin Auton Res*. 2011;21:117-20.

109. Pierpont GL, Voth EJ. Assessing autonomic function by analysis of heart rate recovery from exercise in healthy subjects. *Am J Cardiol*. 2004;94:64-8.

110. Lauer MS, Froelicher V. Abnormal heart-rate recovery after exercise. *Lancet.* 2002; 360:1176-7.

111. Lauer M, Froelicher ES, Williams M, Kligfield P. Exercise testing in asymptomatic adults: a statement for professionals from the American Heart Association Council on Clinical Cardiology, Subcommittee on Exercise, Cardiac Rehabilitation, and Prevention. *Circulation.* 2005;112:771-6.

112. Cole CR, Blackstone EH, Pashkow FJ, Snader CE, Lauer MS. Heart-rate recovery immediately after exercise as a predictor of mortality. *N Engl J Med*. 1999;341:1351-7.

113. Nishime EO, Cole CR, Blackstone EH, Pashkow FJ, Lauer MS. Heart rate recovery and treadmill exercise score as predictors of mortality in patients referred for exercise ECG. *JAMA*. 2000;284:1392-8.

114. Cheng YJ, Lauer MS, Earnest CP, Church TS, Kampert JB, Gibbons LW, *et al.* Heart rate recovery following maximal exercise testing as a predictor of cardiovascular disease and all-cause mortality in men with diabetes. *Diabetes Care.* 2003;26:2052-7.

115. Lipinski MJ, Vetrovec GW, Froelicher VF. Importance of the first two minutes of heart rate recovery after exercise treadmill testing in predicting mortality and the presence of coronary artery disease in men. *Am J Cardiol.* 2004;93:445-9.

116. Nanas S, Anastasiou-Nana M, Dimopoulos S, Sakellariou D, Alexopoulos G, Kapsimalakou S, *et al.* Early heart rate recovery after exercise predicts mortality in patients with chronic heart failure. *Int J Cardiol*. 2006;110:393-400.

117. Bilsel T, Terzi S, Akbulut T, Sayar N, Hobikoglu G, Yesilcimen K. Abnormal heart rate recovery immediately after cardiopulmonary exercise testing in heart failure patients. *Int Heart J*. 2006;47:431-40.

118. Syme AN, Blanchard BE, Guidry MA, Taylor AW, Vanheest JL, Hasson S, *et al.* Peak systolic blood pressure on a graded maximal exercise test and the blood pressure response to an acute bout of submaximal exercise. A*m J Cardiol*. 2006;98:938-43.

119. Cohen-Solal A, Laperche T, Morvan D, Geneves M, Caviezel B, Gourgon R. Prolonged kinetics of recovery of oxygen consumption after maximal graded exercise in patients with chronic heart failure: Analysis with gas exchange measurements and NMR spectroscopy. *Circulation*. 1995;91:2924-32.

120. Harris RC, Edwards RH, Hultman E, Nordesjö LO, Nylind B, Sahlin K. The time course of phosphorylcreatine resynthesis during recovery of the quadriceps muscle in man. *Pflugers Arch*. 1976;367:137-42.

121. Maehlum S, Grandmontagne M, Newsholme EA, Sejersted OM. Magnitude and duration of excess post exercise oxygen consumption in healthy young subjects. *Metabolism.* 1986;35:425-9.

122. Bahr R, Ingnes I, Vaage O, Sejersted OM, Newsholme EA. Effect of duration of exercise on excess post-exercise oxygen consumption. *J Appl Physiol.* 1987;62:485-90.

123. De Groote P, Millaire A, Decoulx E, Nugue O, Guimier P, Ducloux G. Kinetics of oxygen consumption during and after exercise in patients with dilated cardiomyopathy: new markers of exercise intolerance with clinical implications. *J Am Coll Cardiol.* 1996;28:168-75.

124. Drezner JA, Ackerman MJ, Anderson J, Ashley E, Asplund CA, Baggish AL, *et al.* Electrocardiographic interpretation in athletes: the 'Seattle criteria'. *Br J Sports Med.* 2013;47:122-4.

125. Johnson NP, Holly TA, Goldberger JJ. QT dynamics early after exercise as a predictor of mortality. *Heart Rhythm*. 2010;7:1077-84.

126. Ainsworth BE, Haskell WL, Herrmann SD, Meckes N, Bassett DR Jr, Tudor-Locke C, *et al.* 2011 Compendium of Physical Activities: a second update of codes and MET values. *Med Sci Sports Exerc.* 2011;43:1575-81.

127. Jezior MR, Kent SM, Atwood JE. Exercise testing in Wolff-Parkinson-White syndrome: case report with ECG and literature review. *Chest.* 2005;127:1454-7.

128. Vasey C, O'Donnell J, Morris S, McHenry P. Exercise-induced left bundle branch block and its relation to coronary artery disease. *Am J Cardiol.* 1985;56:892-5.

129. Wasserman K, Hansen JE, Sue DY, Casaburi R, Whipp BJ, eds. *Principles of exercise testing and interpretation.* Third edition. Baltimore: Lippincott Williams&Wilkins, 1999.

130. Franco Bonafonte L, Rubio Pérez FJ. Gasto energético en el humano. Calorimetría indirecta. Medición del consumo de oxígeno. En Naranjo Orellana J, Santalla Hernández A, Manonelles Marqueta P, eds. *Valoración del rendimiento del deportista en el laboratorio.* Barcelona: Esmon Publicidad, 2013;89-111.

131. Santalla Hernández A. Relaciones del VO_2max con otras variables. Eficiencia mecánica y respuesta del VO_2 a carga constante. En Naranjo Orellana J, Santalla Hernández A, Manonelles Marqueta P, eds. *Valoración del rendimiento del deportista en el laboratorio.* Barcelona: Esmon Publicidad, 2013;313-33.

132. Buchfuhrer MJ, Hansen JE, Robinson TE, Sue DY, Wasserman K, Whipp BJ. Optimizing the exercise protocol for cardiopulmonar assessment. *J Appl Physiol Respir Environ Exerc Physiol*. 1983;55:1558-64.

133. Santalla Hernández A. Consumo máximo de oxígeno en el deportista. Factores determinantes. Importancia para el rendimiento. En: Naranjo Orellana J, Santalla Hernández A, Manonelles Marqueta P, eds. *Valoración del rendimiento del deportista en el laboratorio*. Barcelona: Esmon Publicidad, 2013;293-312.

134. Yoon B-K, Kravitz L, Robergs R. VO2max, protocol duration and the VO_2 plateau. *Med Sci Sports Exerc.* 2007;39:1186-92.

135. Beltrami FG, Froyd C, Mauger A, Metcalfe A, Marino F, Noakes TD. Conventional testing methods produce submaximal values of maximal oxygen consumption. *Br J Sports Med.* 2012;46:23-9.

136. Mauger A, Sculthorpe N. A new O_2max protocol allowing self-pacing in maximal incremental exercise. *Br J Sports Med*. 2012;46:59-63.

137. Smirmaul BC, Bertucci DC, Teixeira IP. Is the VO_2max that we measure really maximal? *Front Physiol*. 2013;4:203.

138. Heyward V. *Advanced fitness assessment and exercise prescription*. Second edition. Champaign IL: Human Kinetics Books, 1991.

139. Franklin BA, Whaley MH, Howley ET, eds. *ACSM's guidelines for exercise testing and prescription.* Sixth edition. Philadelphia: Lippincott Williams & Wilkins, 2000.

140. Wasserman K, McIlroy MB. Detecting the threshold of anaerobic metabolism in cardiac patients during exercise. *Am J Cardiol.* 1964;14:844-52.

141. López Chicharro J, Aznar Laín S, Fernández Vaquero A, López Mojares LM, Lucía Mulas A, Pérez Ruiz M. Transición aeróbico-anaeróbica. *Concepto, metodología de determinación y aplicaciones.* Madrid: Master Line y Prodigio SL, 2004.

142. Galilea Ballarini PA, Riera Canals J, Drobnic Martínez F. Comportamiento de la ventilación en una prueba incremental. El modelo trifásico. Significado y utilidad de los umbrales ventilatorios. En: Naranjo Orellana J, Santalla Hernández A, Manonelles Marqueta P, eds. *Valoración del rendimiento del deportista en el laboratorio.* Barcelona: Esmon Publicidad, 2013;337-46.

143. Skinner JS, McLellan TH. The transition from aerobic to anaerobic metabolism. *Res Q Exerc Sport.* 1980;51:234-48.

144. López Chicharro J, Fernández Vaquero A, eds. F*isiología del ejercicio.* 3ª edición. Buenos Aires: Editorial Médica Panamericana, 2006.

145. Meyert T, Faude O, Sharhag J, Urhausen A, Kindermann W. Is lactic acidosis a cause of exercise induced hyperventilation at the respiratory compensation point? *Br J Sports Med*. 2004;38:622-5.

146. Smith EE, Guyton AC, Manning RC, White RJ. Integrated mechanisms of cardiovascular response and control during exercise in the normal human. *Prog Cardiovasc Dis* 1976;18:421-44.

147. Robergs RA, Landwehr R. The surprising history of the "HRmax=220-age" equation. *Journal of Exercise Physiology Online*. 2002;5:1-10.

148. Franklin BA, Whaley MH, Howley ET, eds. *ACSM's guidelines for exercise testing and prescription.* Sixth edition. Philadelphia: Lippincott Williams and Wilkins, 2000.

149. Bourdon P. Blood lactate thresholds: concepts and applications. En Tanner RK, Gore CJ, eds. P*hysiological tests for elite athletes.* Second edition. Champaign: Human Kinetics, 2013;77-102.

150. Banister EW, Allen ME, Mekjavic IB, Singh AK, Legge B, Mutch BJC. The time course of ammonia and lactate accumulation in blood during bicycle exercise. *Eur J Appl Physiol*.1983;51:195-202.

151. Kantanista A, Kusy K, Zarębska E, Włodarczyk M, Ciekot-Sołtysiak M, Zieliński J. Blood ammonia and lactate responses to incremental exercise in highly-trained male sprinters ad triathletes. *Biomedical Human Kinetics.* 2016;8:32-8.

152. Gorostiaga EM, Navarro-Amézqueta I, Calbet JA, Sánchez-Medina L, Cusso R, Guerrero M, *et al.* Blood ammonia and lactate as markers of muscle metabolites during leg press exercise. *J Strength Cond Res.* 2014;28:2775-85.

153. Salas-Heredia E, Clarí R, Almenar MV, Senabre-Gallego JM, Santos-Soler G, Pons A, *et al.* Utilidad clínica de la determinación de lactato y amonio, en el estudio de la intolerancia al ejercicio. *Rev Sociedad Val Reuma*. 2015,6;1:3-8.

154. Pedersen BK, Febbraio MA. Muscle as an endocrine organ: focus on muscle-derived interleukin-6. *Physiol Rev*. 2008;88:1379-406.

155. Pedersen BK, Akerström TC, Nielsen AR, Fischer CP. Role of myokines in exercise and metabolism. *J Appl Physiol*. (1985) 2007;103:1093-8.

156. Fischer CP. Interleukin-6 in acute exercise and training: what is the biological relevance? *Exerc Immunol Rev* 2006;12:6-33.

157. Helge JW, Stallknecht B, Pedersen BK, Galbo H, Kiens B, Richter EA. The effect of graded exercise on IL-6 release and glucose uptake in human skeletal muscle. *J Physiol.* 2003;546(Pt 1):299-305.

158. Sleivert G. Aerobic assessment. guidelines for athlete assessment in New Zealand sport. En: Bailey C, ed. *Guidelines for athlete assessment in New Zealand sport.* Auckland. New Zealand Hockey Federation Inc. 2002.

159. Kligfield P, Lauer MS. Exercise Electrocardiogram testing: Beyond de ST Segment. *Circulation*. 2006;114:2070-82.

160. Miller TD. Exercise tredmill test: estimating cardiovascular prognosis. *Cleve Clin J Med.* 2008;75:424-30.

161. Mark DB. Risk stratification in patients wiht chest pain. *Prim Care.* 2001;28:99-118.

162. Kodama S. Saito K, Tanaka S, Maki M, Yachi Y, Asumi M, Sugawara A, *et al.* Cardiorespiratory fitness as a quantitative predictor of all-cause mortality and cardiovascular events in healthy men and women: a meta-analysis. *JAMA*. 2009;301:2024-35.

163. Gupta S, Rohatgi A, Ayers CR, Willis BL, Haskell VL, Khera A, *et al.* Cardiorespiratory fitness and classification of risk of cardiovascular disease mortality. *Circulation.* 2011;123:1377-83.

164. Mayers J, Prakash M, Froelicher V, Do D, Partigton S, Atwood JE. Exercise capacity and mortality among men refered for exercise testing. *N Engl J Med*. 2002;346:793-801.

165. Wackers FJ. Customized exercise testing. *J Am Coll Cardiol*. 2009;54:546-8.

166. Kim ES, Ishwaran H, Blackstone E, Lauer MS. External prognostic validations and comparisons of age- and gender adjusted exercise capacity predictions. *J Am Coll Cardiol.* 2007;50:1867-75.

167. Morris CK, Myers J, Froelicher VF, Kawaguchi T, Ueshima K, Hideg A. Nomogram based on metabolics equivalent and age for assessing aerobic exercise capacity in men. *J Am Coll Cardiol.* 1993;22:175-82.

168. Lauer MS, Francis GS, Okin PM, Pashkow FJ, Snader CE, Marwick TH. Impaired chronotropic response to exercise stress testing as a predictor of mortality. *JAMA*. 1999;281:524-9.

169. Gulati M, Shaw LJ, Thisted RA, Black HR, Bairey Merz CN, Arnsdorf MF. Heart rate response to exercise stress testing in asymptomatic women: the st. James women take heart project. *Circulation*. 2010;122:130-7.

170. Brawner CA, Ehrman JK, Schairer JR, Cao JJ, Keteyian SJ. Predicting máximum heart rate among patients with coronary heart disease receiving beta-adrenergic blockade therapy. *Am Heart J*. 2004;148:910-4.

171. Wiens RD, Lafia P, Marder CM, Evans RG, Kennedy HL. Chronotropic incompetence in clinical exercise testing. *Am J Cardiol*. 1984;54:74-8.

172. Azarbal B, Hayes SW, Lewin HC, Hachamovitch R, Cohen I, Berman DS. The incremental prognostic value of percentage of heart rate reserve achieved over myocardial perfusion single-photon emission computed tomography in the prediction of cardiac death and all-cause mortality: superiority over 85% of maximal age-predicted heart rate. *J Am Coll Cardiol.* 2004;44:423-30.

173. Daugherty SL, Magid DJ, Kikla JR, Hokanson JE, Baxter J, Ross CA, *et al.* Gender differences in the prognostic value of exercise treadmill test characteristics. *Am Heart J.* 2011;161:908-14.

174. Jouven X, Empana JP, Schwartz PJ, Desnos M, Courbon D, Ducimetiere P. Heart rate profile during exercise as a predictor of sudden death. *N Engl J Med.* 2005;352:1951-8.

175. Lee VV, Mitiku T, Sungar G, Meyers J, Froelicher V. The blood pressure response, to dynamic exercise testing: a systematic review. *Prog Cardiovasc Dis.* 2008;51:135-60.

176. Ha JW, Juracan EM, Mahoney DW, Oh JK, Shub C, Seward JB, *et al.* Hypertensive response to exercise: a potential cause, for new wall motion, abnormality in the absence of coronary artery disease. *J Am Coll Cardiol.* 2002;39:323-7.

177. Huang CL, Su TC, Chen WJ, Lin LY, Wang WL, Feng MH, *et al.* Usefulness of paradoxical systolic blood pressure increase after exercise as a predictor of cardiovascular mortality. *Am J Cardiol.* 2008;102:518-23.

178. Dewey FE, Kapoor JR, Williams RS, Lipinsky MJ, Ashley EA, Hadley D, *et al.* Ventricular arrhythmias durin clinical treadmill testing and prognosis. *Arch Intern Med.* 2008;168:225-34.

179. Eckart RE, Field ME, HruzcKowski TW, Forman DE, Dorbala S, Di Carli MF, *et al.* Association of electrcardiogrphic morphology of exercise-induced ventricular arrhythmia with mortality. *Ann Intern Med.* 2008;149:451-60.

180. Maas AH, van der Schouw YT, Regitz-Zagrosek V, Swahn E, Appelman YE, Pasterkamp G, *et al.* Red alert for women's heart: the urgent need for more research and knowledge on cardiovascular disease in women: proceedings of the workshop held in Brussels on gender differences in cardiovascular disease, 29 September 2010. *Eur Heart J.* 2011;32:1362-8.

181. Corrado D, Pelliccia A, Heidbuchel H, Sharma S, Link M, Basso C, *et al.* Section of Sports Cardiology, European Association of Cardiovascular Prevention and Rehabilitation. Recommendations for interpretation of 12-lead electrocardiogram in the athlete. *Eur Heart J.* 2010;31:243-59.

182. Marijon E, Bougouin W, Celermajer DS, Périer MC, Dumas F, Benameur N, *et al.* Characteristics and outcomes of sudden cardiac arrest during sports in women. *Circ Arrhythm Electrophysiol.* 2013;6:1185-91.

183. Anand SS, Islam S, Rosengren A, Franzosi MG, Steyn K, Yusufali AH, *et al;* INTERHEART Investigators. Risk factors for myocardial infarction in women and men: insights from the INTERHEART study. *Eur Heart J.* 2008;29:932-40.

184. Towfighi A, Zheng L, Ovbiagele B. Sex-specific trends in midlife coronary heart disease risk and prevalence. *Arch Intern Med.* 2009;169:1762-6.

185. Mieres JH, Gulati M, Bairey Merz N, Berman DS, Gerber TC, Hayes SN, *et al;* American Heart Association Cardiac Imaging Committee of the Council on Clinical Cardiology; Cardiovascular Imaging and Intervention Committee of the Council on Cardiovascular Radiology and Intervention. Role of noninvasive testing in the clinical evaluation of women with suspected ischemic heart disease: a consensus statement from the American Heart Association. *Circulation*. 2014;130:350-79.

186. Kwok Y, Kim C, Grady D, Segal M, Redberg R. Meta-analysis of exercise testing to detect coronary artery disease in women. *Am J Cardiol*. 1999;83:660-6.

187. Kohli P, Gulati M. Exercise stress testing in women: going back to the basics. *Circulation.* 2010;122:2570-80.

188. Gianrossi R, Detrano R, Mulvihill D, Lehmann K, Dubach P, Colombo A, *et al.* Exercise-induced ST depression in the diagnosis of coronary artery disease. A meta-analysis. *Circulation*. 1989;80:87-98.

189. Sanders GD, Patel MR, Chatterjee R, Ross AK, Bastian LA, Coeytaux RR, Heidenfelder BL, Musty MD, Dolor RJ. Rockville (MD): Agency for Healthcare Research and Quality (US); 2013 Feb. Report No.: 13-EHC072-EF. AHRQ Future Research Needs Papers. Noninvasive technologies for the diagnosis of coronary artery disease in women: future research needs: identification of future research needs from comparative effectiveness review No. 58 [Internet].

190. Cumming GR, Dufresne C, Kich L, Samm J. Exercise electrocardiogram patterns in normal women. *Br Heart J.* 1973;35:1055-61.

191. Higgins JP, Higgins JA. Electrocardiographic exercise stress testing: an update beyond the ST segment. *Int J Cardiol.* 2007;116:285-99.

192. Morise AP, Beto R. The specificity of exercise electrocardiography in women grouped by estrogen status. *Int J Cardiol.* 1997;60:55-65.

193. Grzybowski A, Puchalski W, Zieba B, Gruchala M, Fijalkowski M, Storoniak K, *et al.* How to improve noninvasive coronary artery disease diagnostics in premenopausal women? The influence of menstrual cycle on ST depression, left ventricle contractility, and chest pain observed during exercise echocardiography in women with angina and normal coronary angiogram. *Am Heart J.* 2008;156:964.e1-964.e5.

194. Robert AR, Melin JA, Detry JM. Logistic discriminant analysis improves diagnostic accuracy of exercise testing for coronary artery disease in women. *Circulation*. 1991;83:1202-9.

195. Mark DB, Lauer MS. Exercise capacity; the prognostic variable that doesn't get enough respect. *Circulation*. 2003;108:1534-6.

196. Arena R, Myers J, Williams MA, Gulati M, Kligfield P, Balady GJ, *et al;* American Heart Association Council on Cardiovascular Nursing. Assessment of functional capacity in clinical and research settings: a scientific statement from the American Heart Association Committee on Exercise, Rehabilitation, and Prevention of the Council on Clinical Cardiology and the Council on Cardiovascular Nursing. *Circulation*. 2007;116:329-43.

197. Gulati M, Black HR, Shaw LJ, Arnsdorf MF, Merz CN, Lauer MS, *et al.* The prognostic value of a nomogram for exercise capacity in women. *N Engl J Med.* 2005;353:468-75.

198. Gulati M, Pandey DK, Arnsdorf MF, Lauderdale DS, Thisted RA, Wicklund RH, *et al.* Exercise capacity and the risk of death in women: the St James Women Take Heart Project. *Circulation.* 2003;108:1554-9.

199. Mora S, Redberg RF, Cui Y, Whiteman MK, Flaws JA, Sharrett AR, *et al.* Ability of exercise testing to predict cardiovascular and all-cause death in asymptomatic women: a 20-year follow-up of the lipid research clinics prevalence study. *JAMA*. 2003;290:1600-7.

200. Roger VL, Jacobsen SJ, Pellikka PA, Miller TD, Bailey KR, Gersh BJ. Prognostic value of treadmill exercise testing: a population-based study in Olmsted County, Minnesota. *Circulation*. 1998;98:2836-41.

201. Bourque JM, Holland BH, Watson DD, Beller GA. Achieving an exercise workload of > or = 10 metabolic equivalents predicts a very low risk of inducible ischemia: does myocardial perfusion imaging have a role? *J Am Coll Cardiol.* 2009;54(6):538-45.

202. Panzer C, Lauer MS, Brieke A, Blackstone E, Hoogwerf B. Association of fasting plasma glucose with heart rate recovery in healthy adults: a population-based study. *Diabetes.* 2002;51:803-7.

203. Vivekananthan DP, Blackstone EH, Pothier CE, Lauer MS. Heart rate recovery after exercise is a predictor of mortality, independent of the angiographic severity of coronary disease. *J Am Coll Cardiol.* 2003;42:831-8.

204. Mark DB, Hlatky MA, Harrell FE Jr, Lee KL, Califf RM, Pryor DB. Exercise treadmill score for predicting prognosis in coronary artery disease. *Ann Intern Med.* 1987;106:793-800.

205. Alexander KP, Shaw LJ, Shaw LK, Delong ER, Mark DB, Peterson ED. Value of exercise treadmill testing in women. *J Am Coll Cardiol.* 1998;32:1657-64.

206. Kwok JM, Miller TD, Hodge DO, Gibbons RJ. Prognostic value of the Duke treadmill score in the elderly. *J Am Coll Cardiol.* 2002;39:1475-81.

207. Shaw LJ, Mieres JH, Hendel RH, Boden WE, Gulati M, Veledar E, *et al;* WOMEN Trial Investigators. Comparative effectiveness of exercise electrocardiography with or without myocardial perfusion single photon emission computed tomography in women with suspected coronary artery disease: results from the What Is the Optimal Method for Ischemia Evaluation in Women (WOMEN) trial. *Circulation*. 2011;124:1239-49.

208. Kemp HG Jr, Vokonas PS, Cohn PF, Gorlin R. The anginal syndrome associated with normal coronary arteriograms. Report of a six year experience. *Am J Med.* 1973;54:735-42.

209. Kaski JC, Crea F, Nihoyannopoulos P, Hackett D, Maseri A. Transient myocardial ischemia during daily life in patients with syndrome X. *Am J Cardiol.* 1986;58:1242-7.

210. Paridon SM, Alpert BS, Boas SR, Cabrera ME, Caldarera LL, Daniels SR, *et al;* American Heart Association Council on Cardiovascular Disease in the Young, Committee on Atherosclerosis, Hypertension, and Obesity in Youth. Clinical stress testing in the pediatric age group: a statement from the American Heart Association Council on Cardiovascular Disease in the Young, Committee on Atherosclerosis, Hypertension, and Obesity in Youth. *Circulation.* 2006;113:1905-20.

211. Massin MM. The role of exercise testing in pediatric cardiology. *Arch Cardiovasc Dis.* 2014;107:319-27.

212. Barker AR, Williams CA, Jones AM, Armstrong N. Establishing maximal oxygen uptake in young people during a ramp cycle test to exhaustion. *Br J Sports Med.* 2011;45:498-503.

213. Tanner CS, Heise CT, Barber G. Correlation of the physiologic parameters of a continuous ramp versus an incremental James exercise protocol in normal children. *Am J Cardiol.* 1991;67:309-12.

214. American Thoracic Society. ATS Statement: guidelines for the six-minute walk test. *Am J Respir Crit Care Med.* 2002;166:111-7.

215. Armstrong N, Welsman JR. Assessment and interpretation of aerobic fitness in children and adolescents. Exerc Sport Sci Rev. 1994;22:435-76.

216. Barker AR, Armstrong N. Exercise testing elite young athletes. *Med Sport Sci.* 2011;56:106-25.

217. Hansen HS, Froberg K, Nielsen JR, Hyldebrandt N. A new approach to assessing maximal aerobic power in children: the Odense School Child Study. *Eur J Appl Physiol.* 1989;58:618-24.

218. Cooper DM, Weiler-Ravell D, Whipp BJ, Wasserman K. Aerobic parameters of exercise as a function of body size during growth in children. *J Appl Physiol.* 1984;56:628-34.

219. Cooper DM, Weiler-Ravell D. Gas exchange response to exercise in children. *Am Rev Respir Dis.* 1984;129(2 Pt 2):S47-8.

220. Nevill AM, Bate S, Holder RL. Modeling physiological and anthropometric variables known to vary with body size and other confounding variables. *Am J Phys Anthropol.* 2005;Suppl 41:141-53.

221. Nevill AM, Holder RL, Baxter-Jones A, Round JM, Jones DA. Modeling developmental changes in strength and aerobic power in children. *J Appl Physiol.* (1985) 1998;84:963-70.

222. Arvidsson D, Slinde F, Hulthén L, Sunnegårdh J. Physical activity, sports participation and aerobic fitness in children who have undergone surgery for congenital heart defects. *Acta Paediatr.* 2009;98:1475-82.

223. Budts W, Börjesson M, Chessa M, Buuren F van, Trindade PT, Corrado D, *et al.* Physical activity in adolescents and adults with congenital heart defects: individualized exercise prescription. *Eur Heart J.* 2013;34:3669-74.

224. Reybrouck T, Weymans M, Stijns H, Van der Hauwaert LG. Exercise testing after correction of tetralogy of Fallot: the fallacy of a reduced heart rate response. *Am Heart J.* 1986;112:998-1003.

225. Pincott ES, Burch M. Indications for heart transplantation in congenital heart disease. *Curr Cardiol Rev.* 2011;7:51.

226. Giardini A, Fenton M, Andrews RE, Derrick G, Burch M. Peak oxygen uptake correlates with survival without clinical deterioration in ambulatory children with dilated cardiomyopathy. *Circulation.* 2011;124:1713-8.

227. Basso C, Maron BJ, Corrado D, Thiene G. Clinical profile of congenital coronary artery anomalies with origin from the wrong aortic sinus leading to sudden death in young competitive athletes. *J Am Coll Cardiol. 200*0;35:1493-501.

228. Jan SL, Hwang B, Fu YC, Lee PC, Kao CH, Liu RS, *et al.* Comparison of 201Tl SPET and treadmill exercise testing in patients with Kawasaki disease. *Nucl Med Commun.* 2000;21:431-5.

229. Kane DA, Fulton DR, Saleeb S, Zhou J, Lock JE, Geggel RL. Needles in hay: chest pain as the presenting symptom in children with serious underlying cardiac pathology. *Congenit Heart Dis.* 2010;5:366-73.

230. Jacobsen JR, Garson A, Gillette PC, McNamara DG. Premature ventricular contractions in normal children. *J Pediatr.* 1978;92:36-8.

231. Wiles HB. Exercise testing for arrhythmia: children and adolescents. *Prog Pediatr Cardiol.* 1993;2:51-60.

232. Priori SG, Wilde AA, Horie M, Cho Y, Behr ER, Berul C, *et al.* HRS/EHRA/APHRS expert consensus statement on the diagnosis and management of patients with inherited primary arrhythmia syndromes: document endorsed by HRS, EHRA, and APHRS in May 2013 and by ACCF, AHA, PACES, and AEPC in June 2013. *Heart Rhythm.* 2013;10:1932-63.

233. Horner JM, Horner MM, Ackerman MJ. The diagnostic utility of recovery phase QTc during treadmill exercise stress testing in the evaluation of long QT syndrome. *Heart Rhythm.* 2011;8:1698-704.

234. Amin AS, de Groot EA, Ruijter JM, Wilde AA, Tan HL. Exercise-induced ECG changes in Brugada syndrome. *Circ Arrhythm Electrophysiol.* 2009;2:531-9.

235. American College of Sports Medicine, Chodzko-Zajko WJ, Proctor DN, Fiatarone Singh MA, Minson CT, Nigg CR, Salem GJ, Skinner JS. American College of Sports Medicine position stand. Exercise and physical activity for older adults. *Med Sci Sports Exerc*. 2009;41:1510-30.

236. Skinner JS. Aging for exercise testing and prescription. In: Skinner JS, ed. *Exercise testing and exercise prescription for special cases: theoretical basis and clinical application.* Philadelphia: Lippincont Williams&Wilkins, 2005;85-99.

237. Singh MA. Exercise and aging. *Clin Geriatr Med.* 2004;20:201-21.

238. American College of Sports Medicine. *Guidelines for exercise testing and prescription.* Fifth edition. Baltimore: Williams&Wilkins,1995.

239. Casaburi R, Porszasz J, Burns MR, Carithers ER, Chang R, Cooper CB. Physiologic benefits of exercise training in rehabilitation of patients with severe chronic obstructive pulmonary disease. *Am J Respir Crit Care Med.* 1997;155:1541-51.

240. Olopade CH, Beck K, Viggiano RW, Bruce A. Exercise limitation and pulmonary rehabilitation in chronic obstructive pulmonary disease. *Mayo Clin Proc*. 1992;67:144-57.

241. O'Donell D, McGuire M, Samis L, Webb KA. The impact of exercise reconditioning on breathlessness in severe chronic airflow limitation. *Am J Respir Crit Care Med.* 1995;152:2005-13.

242. Womack CJ, Sieminski DJ, Katzel LI, Yataco A, Gardner AW. Improved walking economy in patients with peripheral arterial occlusive disease. *Med Sci Sports Exerc.* 1997;29:1286-90.

243. Barnard J. Physical activity, fitness and claudication. En: Bouchard C, Sepherd RJ, Stephens T, eds. *Physical activity, fitness and health. International proceedings and consensus statement*. Champaign, IL: Human Kinetics Publishers, 1994;633-55.

244. Balady GJ, Weiner DA, Rose L, Ryan TJ. Physiologic responses to arm ergometry exercise relative to age and gender. *J Am Coll Cardiol.* 1990;16:130-5.

245. Lakatta EG, Levy D. Arterial and cardiac aging: major shareholders in cardiovascular disease enterprises: Part I: aging arteries: a "set up" for vascular disease. *Circulation.* 2003;107:139-46.

246. Blacher J, Staessen JA, Girerd X, Gasowski J, Thijs L, Liu L, *et al.* Pulse pressure not mean pressure determines cardiovascular risk in older hypertensive patients. *Arch Intern Med.* 2000;160:1085-9.

247. Wilmore JH, Costill DL. Aging and the older athlete. En Wilmore JH, Costill DL, eds. *Physiology of sport and exercise.* Champaign: Human Kinetics, 1994; 424-41.

248. Heyn P, Abreu BC, Ottenbacher KJ. The effects of exercise training on elderly persons with cognitive impairment and dementia: a meta-analysis. *Arch Phys Med Rehabil.* 2004;85:1694-704.

249. American College of Sports Medicine. *ACSM's Guidelines for exercise testing and prescription.* 8th ed. Baltimore: Lippincott Williams&Wilkins, 2009.

250. Busby MJ, Shefrin EA, Fleg JL. Prevalence and long-term significance of exercise-induced frequent or repetitive ventricular ectopic beats in apparently healthy volunteers. *J Am Coll Cardiol.* 1989;14:1659-65.

251. Maurer MS, Shefrin EA, Fleg JL. Prevalence and prognostic significance of exercise-induced supraventricular tachycardia in apparently healthy volunteers. *Am J Cardiol.* 1995;75:788-92.

252. Hakola L, Komulainen P, Hassinen M, Savonen K, Litmanen H, Lakka TA, *et al.* Cardiorespiratory fitness in aging men and women: the DR's EXTRA study. *Scand J Med Sci Sports.* 2011;21:679-87.

253. Fioretti P, Deckers JW, Brower RW, Simoons ML, Beelen JA, Hugenholtz PG. Predischarge stress test after myocardial infarction in the old age: results and prognostic value. *Eur Heart J.* 1984;5(supl E):101-4.

254. Ciaroni S, Delonca J, Righetti A. Early exercise testing after acute myocardial infarction in the elderly: clinical evaluation and prognostic significance. *Am Heart J.* 1993;126:304-311.

255. Goraya TY, Jacobsen SJ, Pellikka PA, Miller TD, Khan A, Weston SA, *et al.* Prognostic value of treadmill exercise testing in elderly persons. *Ann Intern Med.* 2000;132:862-70.

256. Fleg JL. Stress testing in the elderly. *Am J Geriatr Cardiol.* 2001;10:308-13.

257. Samek L, Betz P, Schnellbacher K. Exercise testing in elderly patients with coronary artery disease. *Eur Heart J.* 1984;5 (suppl E):69-73.

258. Glover DR, Robinson CS, Murray RG. Diagnostic exercise testing in 104 patients over 65 years of age. *Eur Heart J.* 1984;5(suppl E):59-61.

259. Josephson RA, Shefrin E, Lakatta EG, Brant LJ, Fleg JL. Can serial exercise testing improve the prediction of coronary events in asymptomatic individuals? *Circulation.* 1990;81:20-4.

260. Banerjee A, Newman DR, Van den Bruel A, Heneghan C. Diagnostic accuracy of exercise stress testing for coronary artery disease: a systematic review and meta-analysis of prospective studies. *Int J Clin Pract.* 2012;66:477-92.

261. Kokkinos P, Myers J, Faselis C, Panagiotakos DB, Doumas M, Pittaras A, *et al*. Exercise capacity and mortality in older man: a 20 year follow-up study. *Circulation.* 2010;122:790-7.

262. Bouzas-Mosquera A, Peteiro J, Broullón FJ, Álvarez-García N, Méndez E, Pérez A, *et al.* Value of exercise echocardiography for predicting mortality in elderly patients. *Eur J Clin Invest. 2*010;40:1122-30.

263. Gibbons RJ, Balady GJ, Bricker JT, Chaitman BR, Fletcher GF, Froelicher VF, *et al;* American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Update the 1997 Exercise Testing Guidelines). ACC/AHA 2002 guideline update for exercise testing: summary article: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines Committee to Update the 1997 Exercise Testing Guidelines). *Circulation.* 2002;106:1883-92.

264. Fletcher BJ, Dunbar SB, Felner JM, Jensen BE, Almon L, Cotsonis G, *et al.* Exercise testing and training in physically disabled men with clinical evidence of coronary artery disease. *Am J Cardiol.* 1994;73:170-4.

265. Balady GJ, Weiner DS, Rothendeler JA, Ryan TJ. Arm exercise-thalium imaging testing for the detection of coronary artery disease. *J Am Coll Cardiol.* 1987;9:84-8.

266. Martin WH, Xian H, Chandiramani P, Bainter E, Klein AJ. Cardiovascular mortality prediction in veterans with arm exercise vs pharmacologic myocardial perfusión imaging. *Am Heart J.* 2015;170:362-70.

267. Agiovlasitis S, Pitetti KH, Guerra M, Fernhall B. Prediction of VO2peak from the 20-m shuttle-run test in youth with Down syndrome. *Adapt Phys Activ Q*. 2011;28:146-56.

268. Bricout VA, Flore P, Eberhard Y, Faure P, Guinot M, Favre-Juvin A. Maximal and submaximal treadmill tests in a young adult with fragile-X syndrome. *Ann Readapt Med Phys*. 2008;51:683-7.

269. Flore P, Bricout VA, van Biesen D, Guinot M, Laporte F, Pépin JL, *et al.* Oxidative stress and metabolism at rest and during exercise in persons with Down syndrome. *Eur J Cardiovasc Prev Rehabil.* 2008;15:35-42.

270. Ordoñez FJ, Rosety MA, Diaz AJ, Rosety I, Camacho A, Fornieles G, *et al.* Lo importante sigue siendo participar: ejercicio y discapacidad intelectual. *Arch Med Deporte*. 2012;148:609-20.

271. Mendonca GV, Pereira FD. Heart rate recovery after exercise in adults with the Down syndrome. *Am J Cardiol.* 2010;105:1470-3.

272. Sionis A, Ruiz-Nodar JM, Fernandez-Ortiz A, Marin F, Abu-Assi E, Diaz-Castro O, *et al.* Actualización en cardiopatía isquémica y cuidados críticos cardiológicos. *Rev Esp Cardiol.* 2015;68:234-41.

273. Espinosa JS, Montañés D. La prueba de esfuerzo convencional en cardiología: Aspectos generales y metodología. En: Espinosa JS, Sánchez-La Fuente C, eds. P*rueba de esfuerzo cardiaca, respiratoria y deportiva.* Barcelona: Edika Med, 2002;33-52.

274. Hurst JW, Morris DC, Alexander RW. The use of the New York Heart Association's classification of cardiovascular disease as part of the patient's complete Problem List. *Clin Cardiol.* 1999;22:385-90.

275. Ruiz P, Wangüemert F. Sensibilidad y valor predictivo negativo de la ergometrıía para el diagnóstico de la taquicardia ventricular polimórfica catecolaminérgica. *Rev Esp Cardiol.* 2015;68:544-7.

276. Ferreira-Gonzalez I. Epidemiología de la enfermedad coronaria. *Rev Esp Cardiol*. 2014;67:139-44.

277. Mancia G, Fagard R, Narkiewicz K, Redon J, Zanchetti A, Bohm M, *et al.* Guía de práctica clínica de la ESH/ESC 2013 para el manejo de la hipertensión arterial. *Rev Esp Cardiol.* 2013;66:880.e1-880.e64.

278. Youn JC, Kang SM. Cardiopulmonary exercise test in patients with hypertension: focused on hypertensive response to exercise. *Pulse (Basel)*. 2015;3:114-7.

279. Zanettini JO, Fuchs FD, Zanettini MT, Zanettini JP. Is hypertensive response in treadmill testing better identified with correction for working capacity? A study with clinical, echocardiographic and ambulatory blood pressure correlates. *Blood Pressure.* 2004;13:225-9.

280. Miyai N, Arita M, Morioka I, Miyashita K, Nishio I, Takeda S. Exercise BP response in subjects with high-normal BP: exaggerated blood pressure response to exercise and risk of future hypertension in subjects with high-normal blood pressure. *J Am Coll Cardiol.* 2000;36:1626-31.

281. McCullough PA, Gallager MJ, Dejon AR, Sandberg KR, Trivax JE, Alexander D, *et al.* Cardiorespiratory fitness and short-term complications after bariatric surgery. *Chest.* 2006;130:517-25.

282. Eagle KA, Berger PB, Calkins H, Chaitman BR, Ewy GA, Fleischmann KE, *et al;* American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Update the 1996 Guidelines on Perioperative Cardiovascular Evaluation for Noncardiac Surgery). ACC/AHA guideline update for perioperative cardiovascular evaluation for noncardiac surgery---executive summary a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Update the 1996 Guidelines on Perioperative Cardiovascular Evaluation for Noncardiac Surgery). *Circulation.* 2002;105:1257-67.

283. McAuley PA, Kokkinos PF, Oliveira RB, Emerson BT, Myers JN. Obesity paradox and cardiorespiratory fitness in 12,417 male veterans aged 40 to 70 years. Mayo Clin Proc. 2010;85:115-21.

284. Serra Grima JR. El entrenamiento de las cualidades físicas fuera del ámbito competitivo y en situaciones especiales. En: Serra Grima JR, ed. *Cardiología en el Deporte. Revisión de casos clínicos.* 2ª ed. Barcelona: Elsevier Masson, 2008;118-21.

285. Schaarup C, Hejlesen OK. A multi-method pilot evaluation of an online diabetes exercise system. *Stud Health Technol Inform*. 2015;210:404-8.

286. Wilmore JH, Costill DL. Obesity, diabetes and physical activity. En Wilmore JH, Costill DL, eds. *Physiology of sport and exercise.* Champaign: Human Kinetics, 1994;508.

287. Rowland TW, Martha PM Jr, Reiter EO, Cunningham LN. The influence of diabetes mellitus on cardiovascular function in children and adolescents. *Int J Sports Med*. 1992;13:431-5.

288. Bhatia LC, Singal R, Jain P, Mishra N, Mehra V. Detection of silent myocardial ischaemia in asymptomatic diabetic patients during treadmill exercise testing. *High Blood Press Cardiovasc Prev.* 2012;19:137-42.

289. Slavich G, Mapelli P, Fregolent R, Slavich M, Tuniz D. Non ST ergometric variables in the diabetic patient and their prognostic significance. *Monaldi Arch Chest Dis.* 2010;74:28-35.

290. Kahn JK, Zola B, Juni JE, Vinik AI. Decreased exercise heart rate and blood pressure response in diabetic subjects with cardiac autonomic neuropathy. *Diabetes Care.* 1986;9:389-94.

291. Chacko KM, Bauer TA, Dale RA, Dixon JA, Schrier RW, Estacio RO. Heart rate recovery predicts mortality and cardiovascular events in patients with type 2 diabetes. *Med Sci Sports Exerc.* 2008;40:288-95.

292. Nylen ES, Kokkinos P, Myers J, Faselis C. Prognostic effect of exercise capacity on mortality in older adults with diabetes mellitus. *J Am Geriatr Soc.* 2010;58:1850-4.

293. Marwick TH, Hordern MD, Miller T, Chyun DA, Bertoni AG, Blumenthal RS, *et al;* Council on Clinical Cardiology, American Heart Association Exercise, Cardiac Rehabilitation, and Prevention Committee; Council on Cardiovascular Disease in the Young; Council on Cardiovascular Nursing; Council on Nutrition, Physical Activity, and Metabolism; Interdisciplinary Council on Quality of Care and Outcomes Research. Exercise training for type 2 diabetes mellitus: impact on cardiovascular risk: a scientific statement from the American Heart Association. *Circulation.* 2009;119:3244-62.

294. Balady GJ, Chaitman B, Driscoll D, Foster C, Froelicher E, Gordon N, *et al.* Recommendations for cardiovascular screening, staffing, and emergency policies at health/fitness facilities. *Circulation.* 1998;97:2283-93.

295. Sicari R. Anti-ischemic therapy and stress testing: pathophysiologic, diagnostic and prognostic implications. *Cardiovasc Ultrasound.* 2004;20;2:14.

296. Mooss AN, Prevedel JA, Mohiuddin SM, Hilleman DE, Sketch MH Sr. Effect of digoxin on ST-segment changes detected by ambulatory electrocardiographic monitoring in healthy subjects. *Am J Cardiol*. 1991;68:1503-6.

297. Sketch MH, Moss AN, Butler ML, Nair CK, Mohiuddin SM. Digoxin-induced positive exercise-tests: their clinical and prognostic significance. *Am J Cardiol.* 1981;48:655-69.

298. Shah BR, McCoy LA, Federspiel JJ, Mudrick D, Cowper PA, Masoudi FA, *et al.* Use of stress testing and diagnostic catheterization after coronary stenting: association of site-level patterns with patient characteristics and outcomes in 247,052 Medicare beneficiaries. *J Am Coll Cardiol.* 2013;62:439-46.

299. Léger L, Boucher R. An indirect continuous running multistage field test: the Université de Montréal track test. *Can J Appl Sport Sci.* 1980;5:77-84.

300. Meyer T, Welter JP, Scharhag J, Kindermann W. Maximal oxygen uptake during field running does not exceed that measured during treadmill exercise. *Eur J Appl Physiol.* 2003;88:387-9.

301. Billat VL, Hill DW, Pinoteau J, Petit B, Koralsztein JP. Effect of protocol on determination of velocity at VO2 max and on its time to exhaustion. *Arch Physiol Biochem*. 1996;104:313-21.

302. García GC, Secchi JD, Antonio JF, Bua N, Santander M, Arcuri CR. Qué utiliza el preparador físico en el campo: el VO2 máx., la velocidad aeróbica máxima o la velocidad final alcanzada: *EF Deportes.com Revista Digital.* 2015; 20(206).

303. Pugh LG. The influence of wind resistance in running and walking and the mechanical efficiency of work against horizontal or vertical forces. *J Physiol.* 1971;213:255-76.

304. Hollmann W, Heck H. Principios de la ergoespirometría. En: Rittel HF, ed. *Sistema cardiorespiratorio y deporte.* Vol. 2. Cali (Colombia). Copiservicio. 1980.

305. Storer TW, Davis JA, Caiozzo VJ. Accurate prediction of VO2max in cycle ergometry. *Med Sci Sports Exerc.* 1990;22:704-12.

306. Neumann G. Capacidad de rendimiento. En: Dirix A, Knuttgen HG, Tittel K, eds. *Libro olímpico de la Medicina Deportiva. Enciclopedia de la medicina deportiva.* Vol 1. Barcelona: Doyma, 1988;99-110.

307. Swain DP, Abernathy KS, Smith CS, Lee SJ, Bunn SA. Target heart rates for the development of cardiorespiratory fitness. *Med Sci Sports Exerc.* 1994;26:112-6.

308. Cazorla G, Leger L. *Comment évaluer et developer vos capacities aérobies.* AREAPAC. 1993.

309. Péronnet F, Thibault G. Mathematical analysis of running performance and world running records. *J Appl Physiol (1985).* 1989;67:453-65.

310. García Verdugo M, Leibar X. *Entrenamiento de la resistencia de los corredores de medio fondo y fondo.* Madrid: Gymnos, 1997;85.

311. Esteve-Lanao J, Lucia A, de Koning JJ, Foster C. How do humans control physiological strain during strenuous endurance exercise? *PLoS One.* 2008;3:e2943.

312. Leger L, Mercier D, Gauvin L. The relationship between % VO2máx and running performance time. En: Landers DM, ed. *Sport and elite performers.* Vol 3. Champaing: Human Kinetics, 1986;113-20.

313. Bannister EW. Modeling elite athletic performance. En: Green HJ, McDougal JD, Wenger H, eds. *Physiological testing of elite athletes.* Champaing: Human Kinetics, 1991;403-24.

314. Foster C, Florhaug JA, Frankiln J, Gottschall L, Hrovatin LA, Parker S, *et al.* A new approach to monitoring exercise training. *J Strength Cond Res*. 2001;15;109-15.

315. American College of Sports Medicine. *ACSM's guidelines manual for exercise testing and prescription.* 7th ed. Baltimore: Lippincott Williams & Wilkins, 2014;464-79.

316. Rodríguez FA. Prescripción de ejercicio y actividad física en personas sanas (I). Principios generales. *Atención Primaria.* 1995;15:68-72.

317. Galilea PA, Riera J, Drobnic F. Curvas de lactato en prueba incremental. Metodología. Umbrales lácticos. Significado fisiológico y aplicaciones al entrenamiento. En: Naranjo Orellana J, Santalla Hernández A, Manonelles Marqueta P, eds. *Valoración del rendimiento del deportista en laboratorio*. Barcelona: Esmon Publicidad, 2013;347-57.

318. Bouchard C, Shephard RJ, Stephens T, Sutton JP, McPherson BD. *Exercise, fitness and health*. Champaign: Human Kinetics,1990;75-102.

319. Taylor RS, Brown A, Ebrahim S, Jolliffe J, Noorani H, Rees K, *et al.* Exercise-based rehabilitation for patients with coronary heart disease: systematic review and meta-analysis of randomized controlled trials. *Am J Med.* 2004;116:682-92.

320. Schmitz KH, Courneya KS, Matthews C, Demark-Wahnefried W, Galvão DA, Pinto BM, *et al;* American College of Sports Medicine. American College of Sports Medicine roundtable on exercise guidelines for cancer survivors. *Med Sci Sports Exerc.* 2010;42:1409-26.

321. Agustí A, Cotes J, Wagner PD. Responses to exercise in lung diseases. En: Roca J, Whipp B, eds. *Exercise testing*. Sheffield. European Respiratory Monograph, 1997;2:32-50.

322. Subirats E, Subirats G, Soteras I. Prescripción de ejercicio físico: indicaciones, posología y efectos adversos. *Med Clín.* 2012;138:18-24.

323. Mercier J, Pérez-Martín A, Bigard X, Ventura R. Muscle plasticity and metabolism effects of exercise and chronic diseases. *Mol Asp Med.* 1999;20:319-73.

324. Swain DP, Leutholtz BC. Exercise prescription. *A case study approach to the ACSM Guidelines.* Champaign: Human Kinetics, 2007;116-7.

325. Ekkekakis P. Let them roam free? Physiological and psychological evidence for the potential of self-selected exercise intensity in public health. *Sports Med.* 2009;39:857-88.

326. Doñate M. Valoración funcional y prescripción de ejercicio en pacientes con cardiopatía. *Arch Med Deporte.* 2013;156:221-6.

327. Franco L, Rubio FJ. Sedentarismo, actividad física y riesgo cardiovascular. En: Millán J, ed. *Medicina Cardiovascular. Arterioesclerosis.* Tomo I. Barcelona: Masson, 2005;445-53.

328. Karvonen M, Vuorima T. Heart rate and exercise intensity during sports activities. Practical application. *Sports Med.* 1989;5:303-12.

329. Morgan F, Battersby A, Weightman AL, Searchfield L, Turley R, Morgan H, *et al.* Adherence to exercise referral schemes by participants - what do providers and commissioners need to know? A systematic review of barriers and facilitators. *BMC Public Health.* 2016 5;16:227.

330. Farrance C, Tsofliou F, Clark C. Adherence to community based group exercise interventions for older people: A mixed-methods systematic review. *Prev Med.* 2016;87:155-66.

331. Huberty JL, Ransdell LB, Sidman C, Flohr JA, Shultz B, Grosshans O, *et al.* Explaining long-term exercise adherence in women who complete a structured exercise program. *Res Q Exerc Sport*. 2008;79:374-84.

332. Sallis JF, Howell MF. Determinants of exercise behaviors. *Exerc Sport Sci Rec.* 1990;18:307-30.

333. Romain AJ, Quéré YA, Roy M, Clotet L, Catherine B, Attalin V. Sultan A, *et al.* Le test de marche de 6 minutes: un outil pour augmenter la motivation et le niveau d'activité physique chez des personnes en surcharge pondérale. *Nutrition Clini Métab.* 2014;28(Suppl 1):S139-S140.

334. Organización Mundial de la Salud. *Recomendaciones mundiales sobre actividad física para la salud.* Noviembre. 2010.

335. Kokkinos P, Myers J. Exercise and physical activity: clinical outcomes and applications. *Circulation.* 2010;122:1637-48.

336. Pedersen BK, Saltin B. Exercise as medicine - evidence for prescribing exercise as therapy in 26 different chronic diseases. *Scand J Med Sci Sports.* 2015;25(Suppl 3):1-72.

337. Gibbons RJ, Balady GJ, Beasley JW, Bricker JT, Duvernoy WF, Froelicher VF, *et al.* ACC/AHA Guidelines for Exercise Testing. A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Exercise Testing). *J Am Coll Cardiol.* 1997;30:260-311.

338. Pool PE, Seagren SC, Salel AF. Effects of diltiazem on serum lipids, exercise performance and blood pressure: randomized, double-blind, placebo-controlled evaluation for systemic hypertension. *Am J Cardiol.* 1985;56:H86-H91.

339. Tomten SE, Kjeldsen SE, Nilsson S, Westheim AS. Effect of alpha 1-adrenoceptor blockade on maximal VO2 and endurance capacity in well-trained athletic hypertensive men. *Am J Hypertens.* 1994;7:603-8.

340. Sui X, LaMonte MJ, Blair SN. Cardiorespiratory fitness and risk of nonfatal cardiovascular disease in women and men with hypertension. *Am J Hypertens.* 2007;20:608-15.

341. Weiss SA, Blumenthal RS, Sharrett AR, Redberg RF, Mora S. Exercise blood pressure and future cardiovascular death in asymptomatic individuals. *Circulation*. 2010;121:2109-16.

342. Weber KT, Janicki JS. Equipment and protocol to evaluate the exercise response. En: Weber KT, Janicki JS, eds. *Cardiopulmonary exercise testing: physiologic principles and clinical applications*. Philadelphia: WB Saunders, 1986;139-50.

343. Tan S, Wang J, Cao L. Exercise training at the intensity of maximal fat oxidation in obese boys. *Appl Physiol Nutr Metab.* 2016;41:49-54.

344. Ho PM, Maddox TM, Ross C, Rumsfeld JS, Magid DJ. Impaired chronotropic response to exercise stress testing in patients with diabetes predicts future cardiovascular events. *Diabetes Care.* 2008;31:1531-3.

345. Gardner AW, Afaq A. Management of lower extremity peripheral arterial disease. *J Cardiopulm Rehabil Prev.* 2008;28:349-57.

346. Green DJ. Exercise training as vascular medicine: direct impacts on the vasculature in humans. *Exerc Sport Sci Rev.* 2009;37:196-202.

347. McDermott MM, Tian L, Liu K, Guralnik JM, Ferrucci L, Tan J, *et al.* Prognostic value of functional performance for mortality in patients with peripheral artery disease. *J Am Coll Cardiol.* 2008;51:1482-9.

348. Jacobs DR Jr, Burke GL, Liu K, Cutter G, Hughes G, Hulley S, *et al.* Relationships of low density lipoprotein cholesterol with age and other factors: a cross-sectional analysis of the CARDIA study. *Ann Clin Res.* 1988;20:32-8.

349. Balady GJ, Larson MG, Vasan RS, Leip EP, O'Donnell CJ, Levy D. Usefulness of exercise testing in the prediction of coronary disease risk among asymptomatic persons as a function of the Framingham risk score. *Circulation*. 2004;110:1920-5.

350. Monda KL, Ballantyne CM, North KE. Longitudinal impact of physical activity on lipid profiles in middle-aged adults: the Atherosclerosis Risk in Communities Study. *J Lipid Res.* 2009;50:1685-91.

351. Achten J, Jeukendrup AE. Optimizing fat oxidation through exercise and diet. *Nutrition.* 2004;20:716-27.

352. Terrados N. Metabolismo energético durante la actividad física. En: J. Gonzalez-Gallego, ed. *Fisiología de la actividad física y del deporte.* Madrid. McGraw-Hill Interamericana. 1992;75-94.

353. Terrados N. Effects of aerobic training in midlife populations. En: Gordon SL, González-Mestre X, Garret WE, eds. *Sports and exercise in midlife.* Rosemont: American Academy of Orthopaedic Surgeons Publ, 1993;309-15.

Appendix 1.1. Emergency medical material. Car of cardiac arrest

1. Defibrillator with DEA cable / pacemaker connected. Defibrillator printer paper. DEA replacement. Electrodes.

2. Conventional material for cures: gauze, plaster, bandages, peripheral dressing, Mefix®, chlorhexidine, latex and vinyl gloves of small, medium and large sizes, needle container.

3. Medications:

3.1. Cardiac arrest medication:
- Epinephrine 1 mg / 1 ml.
- Adenosine triphosphate 6 mg / 2 ml.
- Lidocaine 2%.
- Hydrocorticosterone 500 mg and distilled water.
- Amiodarone 150 mg / 3 ml.
- Etomidate 20 mg / 10 ml.
- Flumazenil 1 mg / 10 ml.
- Glucose at 33% 10 ml.
- Naloxone 0.4 mg / ml.
- Midazolam 5 mg / 5 ml.
- Propofol at 1% 20 ml.

3.2. Pre-and post-cardiac infarction medication:
- Biperidene.
- Diazepam 10 mg / 2 ml.
- Digoxin 0.25 mg / ml.
- Dobutamine 250 mg / 20 ml.
- Dopamine 200 mg / 5 ml.
- Furosemide.
- Methylprednisolone 40 mg / 2 ml.
- Nitroglycerin 50 mg / 10 ml.
- Calcium chloride at 10% 10 ml.
- Salbutamol (nebulization).
- Magnesium Sulphate at 15% 10 ml.
- Morphic chloride at 1%.
- Solvent: physiological saline solution 10 cc.
- Antiemetic: metoclopramide 2 ml ampoules = 10 mg.
- In a refrigerator: cisatracurium 10 mg / 5 ml and succinylcholine 100 mg / 2 ml.

3.3. Circulatory Support:
- Number 21 introcan.
- Number 16, 18, 20 and 22 cannulas.
- Intravenous needles.
- Disposable syringes of 1, 5, 10 and 20 ml.
- Whey and droplet serum equipment.
- Dosi-Flow®.
- Extension and three-way line.
- IVAC 591 equipement.
- Venoject® and Vacutainer® adapter.
- Red caps.
- Analytical tube.
- Glucose saline solution at 5%, 10% and 50%.
- Physiological saline solution at 0.9%.
- Voluven® 6% 500 cc.
- Sodium bicarbonate 1 M 250 cc.

3.4. Air support:
- Laryngoscopy. New batteries and replacement bulb.
- Mandrel.
- Magill Clamp.
- Silicone lubricant.
- Syringes of 20 and 50 ml.
- Bandages.
- Guedel tube numers 2, 3, 4 and 5.
- Orotracheal tubes or laryngeal masks: 6.5, 7, 7.5, 8 and 8.8.
- Oxygen.
- Adult VMK.
- VMK reserve.
- Nebulizing chamber.
- Suction probes 13 and 14.
- Salem nasogastric probe of number 18.
- Bag valve mask, filter and oxygen connection.
- Ambu masks of numbers 3, 4 and 5.
- Oxygen tank.
- Vaccum.

Appendix 1.2. Emergency medical material. Basic

1. Defibrillator with DEA cable / pacemaker connected. Defibrillator printer paper. DEA replacement. Electrodes.

2. Conventional material for cures: gauze, plaster, bandages, peripheral dressing, Mefix®, chlorhexidine, latex and vinyl gloves of small, medium and large sizes, needle container.

3. Medications:

   3.1. Cardiac arrest medication:
   - Epinephrine 1 mg / 1 ml.
   - Atropine 1 mg / 1 ml.
   - Lidocaine 2%.
   - Amiodarone 150 mg / 3 ml.

   3.2. Pre-and post-cardiac infarction medication:
   - Diazepam 10 mg / 2 ml.
   - Methylprednisolone 40 mg / 2 ml.
   - Nitroglycerin 50 mg / 10 ml.
   - Salbutamol (nebulization).
   - Acetylsalicylic acid100-300 mg.

   3.3. Circulatory Support:
   - Number 18 and 20 cannulas.
   - Intravenous needles.
   - Disposable syringes of 1, 5, 10 and 20 ml.
   - Glucose saline solution at 5%.

   3.4. Air support:
   - Guedel tube numers 2, 3, 4 and 5.
   - Laryngeal masks: 4, 5.
   - Adult VMK o Nasal cannulas for oxygen.
   - Suction probes 13 and 14.
   - Bag valve mask, filter and oxygen connection.
   - Ambu masks of numbers 3, 4 and 5.
   - Oxygen tank.
   - Vaccum.

Appendix 1.3. Informed consent document for stress test

Name and description of the procedure: STRESS TEST

It is a test that has two fundamental reasons for being performed. Firstly, for diagnostic or prognostic purposes for patients with heart disease or with suspected coronary artery disease. Secondly, for purposes of functional assessment of the response to physical exercise, in athletes and other practitioners of physical activity, sport or not. In both cases, the exercise test allows checking the heart's response to controlled physical exercise (ergometry). It also serves to assess the overall capacity of your body to this effort and to be able to measure, if appropriate, the consumption of oxygen breathed.

It is done by walking on a treadmill, pedaling on an exercise bike or on a specific ergometer. In the meantime, the speed, slope or both of the treadmill, or the load level of the bicycle or the ergometer, are increased progressively in determined periods of time. Throughout the examination, blood pressure, heart rate and electrocardiogram are monitored to analyze their variations. The test will stop if symptoms or alarming signs appear.

Reasonable alternatives

It is practically impossible to assess the functional situation in a person's effort without subjecting it to a scheduled effort. However, data can be obtained indirectly or with other examinations such as electrocardiogram, isotopic tests, etc. However, this scan is preferably indicated in your case.

Consequences

The effort will cause fatigue and sweating in relation to the intensity of the effort made. There could be some muscle discomfort.

Risks

Muscle tiredness, dizziness, chest angina, leg pain or signs (high blood pressure) that will be alleviated or will disappear after physical activity. In certain cases, especially in major coronary artery disease and other heart diseases, severe heart rhythm disorders, syncope and very occasionally myocardial infarction or heart failure may occur. The risk of death is exceptional (1 per 10,000).

In its current clinical state, the benefits derived from performing this test outweigh the possible risks. For this reason the convenience of being practiced is indicated to you. If complications occur, the medical and nursing staff who is attending you are trained and have the means to try to solve them.

Custom Risks

Patient Statement

The doctor who signs this document has informed me in a satisfactory way about the purpose of the procedure to be performed, what it consists of and how it is going to be carried out. I have been informed of the relevant or important consequences of the procedure. I have been informed about the typical risks of the procedure, as well as those that, although infrequent but not exceptional, have the clinical consideration of very serious. I have also been informed of the personalized risks according to my own characteristics and, at the possible discomfort of the procedure and its consequences.

I declare that I have received information about all indicated in the previous sections, as well as different alternatives to the procedure, with pros and cons, so that, with this information, I participate in the choice of procedure to be performed, being the most appropriate to my preferences .

I am satisfied with the information received, I have obtained information on the doubts that I have raised and I am aware of the possibility of revoking consent at any time without any cause. Therefore, I express my consent to submit to the procedure.

Consent through legal representative (patient's disability)

As the legal representative of the patient I have been informed of all the points contained in this informed consent document and I consent to the procedure.

Date: _______________

Patient:	Doctor:	Witness:	Legal representative:
Name:	Name:	Name:	Name:
ID:	Collegiate number:	ID:	ID:
Signed:	Signed:	Signed:	Signed:

Revocation of consent

After being informed of the nature and risks of the procedure, my refusal / revocation (cross out what is not appropriate) for carrying out the procedure described, making me responsible for the consequences that may arise from this decision.

Date: _______________

Patient:	Doctor:	Witness:	Legal representative:
Name:	Name:	Name:	Name:
ID:	Collegiate number:	ID:	ID:
Signed:	Signed:	Signed:	Signed:

Authors list

Pedro Manonelles Marqueta *(Coordinator)*
PhD at University of Zaragoza. Specialist in Medicine of Physical Education and Sport. Extraordinary Professor and Director of the International Chair of Sports Medicine. Catholic University of Murcia. UCAM. President of the Spanish Society of Sports Medicine (SEMED-FEMEDE). Zaragoza.

Daniel Brotons Cuixart
Medicine PhD. Specialist in Medicine of Physical Education and Sport. Deputy of the Sports and Health Unit. Catalonia Council of Sport. Generalitat de Catalunya. Unit of Sports Medicine of Clinical Ergodynamics and Diagonal Clinic. Barcelona.

José Calabuig Nogués
Specialist in Cardiology. Director of Interventional Cardiology. University of Navarra Clinic. Lecturer of Cardiology and Sports Medicine. Faculty of Medicine. University of Navarra. Pamplona.

Carmen Calderón Soto
Specialist in Medicine of Physical Education and Sport. Head of the Sports Medicine Unit of the High Performance Center of Sierra Nevada. Superior Council of Sports. Granada.

Carlos De Teresa Galván
Sports Medical consultant of the Center for Sports Medicine of Andalucia (CAMD). Lecturer of the Department of Physiology. University of Granada. Granada.

Miguel Del Valle Soto
Professor of the Faculty of Medicine. Oviedo University. Oviedo.

Vicente Elías Ruiz
Specialist in Medicine of Physical Education and Sport. Doctor of the Center for Sports Technology (CTD). Government of La Rioja. Logroño.

Luis Franco Bonafonte *(Coordinator)*
PhD in medicine. Specialist in Medicine of Physical Education and Sport. Unit of Sports Medicine. University Hospital Sant Joan de Reus. Associated lecturer. Faculty of Medicine. Rovira i Virgili University. Reus (Tarragona).

Piero Galilea Ballarini
Doctor. Specialist in Medicine of Physical Education and Sport. Doctor of the Department of Physiology of the High Performance Center of Sant Cugat del Vallés. Lecturer of the faculty of Sports Medicine of Barcelona. Lecturer of Sports Physiology at the School of Physiotherapy Gimbernat. Doctor of the Mapfre Clinic of Tennis Medicine. Barcelona.

Mercedes Galindo Canales
PhD in medicine. Specialist in Medicine of Physical Education and Sport. Doctor at the Laboratory of Exercise Physiology of the Faculty of Sports Sciences at the Polytechnic University of Madrid. Lecturer of the Professional School of Medicine of Physical Education and Sport at the University Complutense of Madrid. Madrid.

Fernando Gutiérrez Ortega
Doctor Specialist in Medicine of Physical Education and Sport. Director of the Center for Sports Medicine of the Spanish Agency for the Protection of Health in Sport (AEPSAD). Madrid.

Fernando Huelin Trillo
Specialist in Medicine of Physical Education and Sport. Director of the Sports Medicine Service of the Galician Sports Tecnification Center (CGTD) of Pontevedra. Pontevedra.

Ricardo Jiménez Mangas
Specialist in Medicine of Physical Education and Sport. National Athletics Coach. Responsible for the Unit of Sports Medicine of the Hospital Quirón-Salud of San Sebastián. San Sebastián (Guipúzcoa).

Emilio Luengo Fernández
Cardiologist. Director of the School of Cardiology of Sport of the Spanish Society of Sports Medicine. Zaragoza.

Begoña Manuz González
Specialist in Medicine of Physical Education and Sport. Sports Medical Center - B. Manuz. Torrelavega (Cantabria).

José Naranjo Orellana *(Coordinator)*
PhD in medicine. Specialist in Medicine of Physical Education and Sport. Lecturer of Exercise Physiology. University Pablo de Olavide. Sevilla.

Fabio Pigozzi
Rector and Lecturer of Internal Medicine. University of Rome Foro Italico. President of the International Federation of Sports Medicine (FIMS). Rome Italy.

Juan Ribas Serna
Professor of Physiology. Department of Medical Physiology and Biophysics. Faculty of Medicine. Sevilla.

Francisco Javier Rubio Pérez
Specialist in Medicine of Physical Education and Sport. Unit of Sports Medicine. Hospital of Amposta-Center of Sports tecnificaition Amposta. Unit of Sports Medicine. University Hospital Sant Joan de Reus. Associated lecturer. Faculty of Medicine. Rovira i Virgili University. Reus (Tarragona).

Luis Segura Casado
Doctor. Specialist in Medicine of Physical Education and Sport. Sports Medicine Service. City council of Tudela. Tudela (Navarra).

Nicolás Terrados Cepeda
PhD of medicine and surgery. Specialist in Medicine of Physical Education and Sport. Director of the Regional Unit of Sports Medicine of Asturias-Municipal Sports Foundation of Avilés. Associated lecturer, Department of Functional Biology. Oviedo University. Oviedo (Asturias).

Carmen Vaz Pardal
Specialist in Medicine of Physical Education and Sport. Center for Sports Medicine of Andalucia. Ministry of Tourism and Sport of the Junta de Andalucía. Cadiz.