Ministry of Higher Education

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College of Medicine/ University of Diyala

The effect of exercise on ECG tests for healthy and unhealthy cases

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Contents

* Abstract

The cardiovascular system include the heart, veins, arteries, and capillaries which all work together to ensure sufficient blood flow to all parts of the body. Ventricular muscle, atrial muscle, and specialized excitatory and conductive muscle fibers all consist the major types of cardiac muscle.

The intracellular potential rises from a very negative value between beats to a slightly positive value within each beat as measured by the action potential in a ventricular muscle fiber.

The cardiac cycle is a sequence of pressure changes in the heart. These pressure changes cause blood to flow through different chambers of the heart and throughout the body. Cardiac cycle events are classified as diastole and systole. Diastole denotes ventricular filling, whereas systole denotes ventricular contraction.

Electrocardiogram is a picture of an electrical conduction of the heart that is taken non-invasively from surface of the body. The right atrium is the first structure to depolarize during normal sinus rhythm, followed by the left atrium.

The first electrical signal on a normal electrocardiogram is known as the P wave, which originates in the atria. Although most leads of an electrocardiogram have only one P wave, the P wave is the sum of electrical signals from the two atria, which are usually superimposed. The electrical depolarisation is then slowed by the atrioventricular (AV) node before proceeding to the ventricles, resulting in a short physiological delay. The PR interval is caused by this delay, which is represented by a straight horizontal or ‘isoelectric' line on the ECG. Because of the greater muscle mass in the ventricles, depolarisation of the ventricles usually results in the largest part of the ECG signal, known as the QRS complex. There is also an electrical signal reflecting myocardium repolarisation in the ventricles. The ST segment and T wave are examples of this. The ST segment is often isoelectric, and T wave in most leads is a variable amplitude and duration upright deflection.

The 12 "leads" ECG are recordings made from pairs or groups of electrodes. They comprise three categories: three dipole limb leads, three augmented voltage limb leads, and six unipole chest leads.

Exercise testing is a type of cardiovascular stress testing in which exercise is combined with electrocardiography (ECG) and blood pressure monitoring. This type of stress testing is usually combined with exercise protocols on a treadmill or bicycle.

Under certain conditions, an exercise ECG test is performed to assess the heart's response to stress or exercise, and it provides a non-invasive, cost-effective, rapid, and reliable prediction of coronary artery disease and cardiac mortality. ECG stress test interpretation should include a combination of history, clinical response to stress, and ECG findings.

*Introduction for physiology of heart

The cardiovascular system supply blood to all parts of the body. It can control the velocity and amount of blood carried through the vessels by responding to various stimuli. The cardiovascular system involve the heart, arteries, veins, and capillaries. The heart and vessels work together to ensure sufficient blood flow to all parts of the body. The cardiovascular system is regulated by a variety of stimuli, which include hormones, changing blood volume, medications, electrolytes, osmolarity, adrenal glands, kidneys, and much more. The parasympathetic and sympathetic nervous systems also play a major role in the regulation of the cardiovascular system.[1][2][3]

The heart is actually consists of two separate pumps: a right heart that pumps blood through the lungs and a left heart that pumps blood through the systemic circulation, which provides blood flow to the rest of the organs and tissues. Each of these pump is a pulsatile two-chamber pump composed of atrium and ventricle.

Each atrium functions as a weak primer pump for the ventricle, assisting in the movement of blood into the ventricle. The ventricles then provide the primary pumping force that propels blood through the pulmonary circulation (right ventricle) or the systemic circulation (left ventricle). Heart rhythmicity is caused by special mechanisms in the heart that transmit action potentials throughout the cardiac muscle to cause the heart's rhythmical beat.[4]

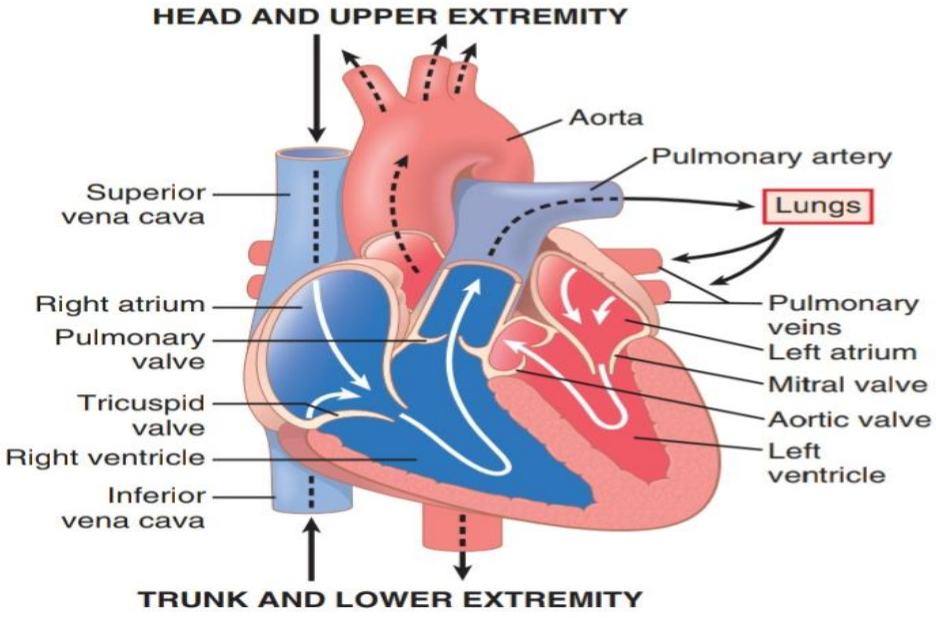


Figure (1). Structure of the heart and course of blood flow through.[4]

*Physiology of cardiac muscle

Atrial muscle, ventricular muscle, and specialized excitatory and conductive muscle fibers are the three major types of cardiac muscle found in the heart. The atrial and ventricular types contract similarly to skeletal muscle, with the exception of a much longer duration of contraction. The heart's specialized excitatory and conductive fibers, on the other hand, contract only weakly because they contain few contractile fibrils; instead, they exhibit either automatic rhythmical electrical discharge in the form of action potentials or conduction of action potentials through the heart, providing an excitatory system that controls the rhythmical beating of the heart.[4]

*Action potential in cardiac muscle

The action potential which is recorded in a ventricular muscle fiber, estimated about 105 millivolts, indicating that the intracellular potential rises from a very negative value, around −85 millivolts, between beats to a slightly positive value, around +20 millivolts, during each beat. Following the initial spike, the membrane remains depolarized for about 0.2 sec, exhibiting a plateau, followed by a sudden repolarizationat at the end of the plateau. The presence of this plateau in the action potential causes the ventricular contraction to last as much as fifteen times as long in cardiac muscle as in skeletal muscle.

The phases of the action potential in cardiac muscle and the ion flows that occur during each phase are ae follow:-

- Phase 0 (depolarization), fast sodium channels open. When the cardiac cell is stimulated and depolarizes, the membrane potential becomes more positive. Voltage-gated sodium channels (fast sodium channels) open and allow the sodium to rapidly flow into the cell and depolarize it. The membrane potential reaches around +20 millivolts before the sodium channels close.
- Phase 1 (initial repolarization), fast sodium channels close. The sodium channels close, the cell start to repolarize, and potassium ions leave the cell through open potassium channels.
- Phase 2 (plateau), the calcium channels open and fast potassium channels close. A brief initial repolarization happen and the action potential then plateaus resulting from elevated calcium ion permeability and decreased potassium ion permeability.

The voltage-gated calcium ion channels open deliberately during phases 0 and 1, and calcium enters the cell. Potassium channels then close, and the combination of decreased potassium ion efflux and elevated calcium ion influx causes the action potential to plateau.

● Phase 3 (rapid repolarization), the calcium channels close and slow potassium channels open. The closure of calcium ion channels and elevated potassium ion permeability, permitting potassium ions to rapidly exit the cell, ends the plateau and returns the cell membrane potential to its resting level.

● Phase 4 (resting membrane potential) estimated around −90 millivolts.[4]

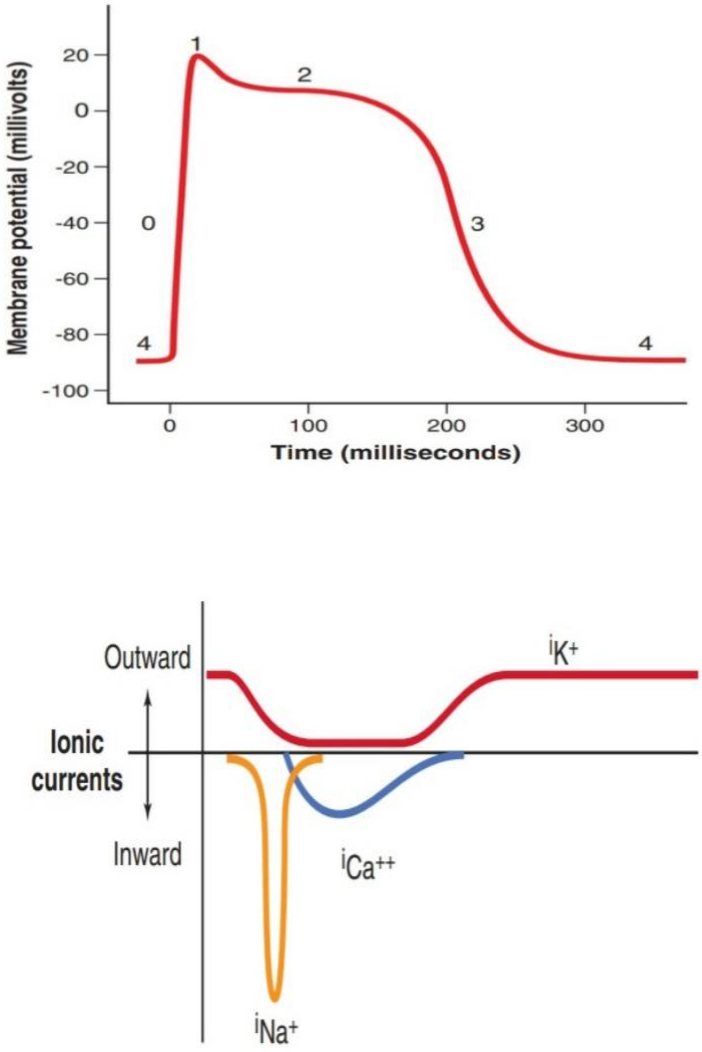


Figure (2). Phases of action potential of cardiac ventricular muscle cell and associated ionic currents for sodium(^{i}Na+),calcium(^{i}Ca++),and potassium (^{i}K+).[4]

*Cardiac cycle

The cardiac cycle is a series of pressure changes that occur within the heart. These pressure changes result in the movement of blood through various chambers of the heart and throughout the body. These changes arises as conductive electrochemical changes within the myocardium which result in the concentric contraction of cardiac muscle. Valves within the heart direct blood movement, leading to organized propulsion of blood to the next chamber.

Cardiac excitation and contraction cause changes in pressure and volume. These changes are directly related to Ca++ ions which entering the myocytes and sustaining the conduction.

Because of this conduction arising at the sinoatrial (SA) node, the atria contract together and then, after a short cessation at the atrioventricular (AV) node, the two ventricles contract together. These contractions arise after a short "lag" concerning the electrical conduction that makes them possible.

This lag result from a time gap between the actual application of the myocardial force and the electrical conduction. In other words, though the depolarization has gone through the myocardium (the electrocardiogram tracing), there is no or little contraction because the depolarization read as the electrical signal is the very beginning of the muscle's movement.[5][6][7][8]

Regarding events of cardiac cycle, it is important to compartmentalize their series. The contraction of the atria (both left and right) normally precede that of the ventricles (both left and right). This contraction series permit the division of the left and right heart, at least functionally, as two separate circuits. Cardiac cycle events can be separated into systole and diastole. Systole represents ventricular contraction and diastole represents ventricular filling. Systole and diastole happen in both the right and left heart, though with very different pressures.

Diastole started with the closing of the aortic valve (or pulmonic) and ends with the closing of the mitral valve (or tricuspid). This period encompasses the relaxation and filling of the ventricle. Diastole represents the blood vessels which return blood to the heart in preparation for the next ventricular contraction.

Systole started when the tricuspid valve (or mitral) closes and concludes with the closure of the pulmonic valve (or aortic). The ventricular contraction, forcing blood into arteries represent this stage of cardiac cycle. When a ventricle contracts, the pressure within the ventricles will become more than adjacent blood vessels, and the valves will permit the blood out. [9][10]

*Normal Electrocardiogram

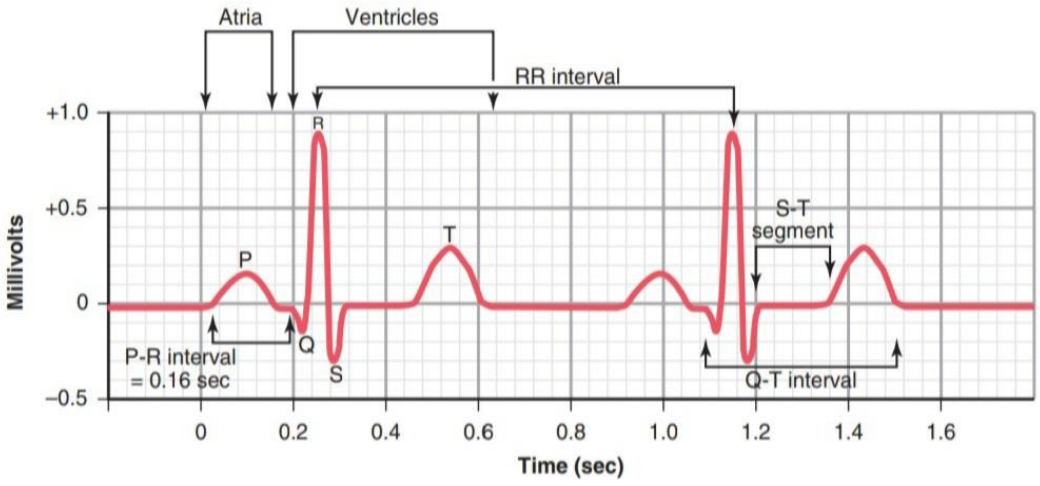
The electrocardiogram (also known as an ECG or EKG) is an electrical trace of the heart that is recorded non-invasively from the surface of the body.[11]

ECG tracing represents the conduction pathway through the heart from a physiological standpoint. Sinus impulses are initiated by the sinoatrial (SA) node, and a wave of depolarization spreads across the right and left atria, forming the P wave. The beat is transmitted to the ventricles via the His bundle, the left and right bundle branches, and the Purkinje system at the atrioventricular node level. The QRS complex is formed as a result of atrial repolarization and early ventricular depolarization.

Ventricular depolarization and subsequent repolarization complete the cycle, resulting in the T-wave. Intervals and segments make up the periods between each complex and wave. The PR, QT, and RR intervals denoted the duration of AV node conduction, the duration of ventricular depolarization to repolarization, and the duration between each cardiac cycle, respectively. The PR and ST segments represent the isoelectric interval between atria and ventricle depolarization and repolarization.[12]

ECG machines are planned to record changes in electrical activity by drawing a trace on electrocardiograph paper that moves at a 25mm/sec .

The time is represented by the x-axis, and the voltage is represented by the y-axis. On the x-axis, 1 second is divided into five large squares, each representing 0.2 sec. Each large square is subdivided into five small squares of 0.04 sec. The EKG machine is calibrated so that a 1 millivolt increase in voltage moves the stylus one centimeter.[13]



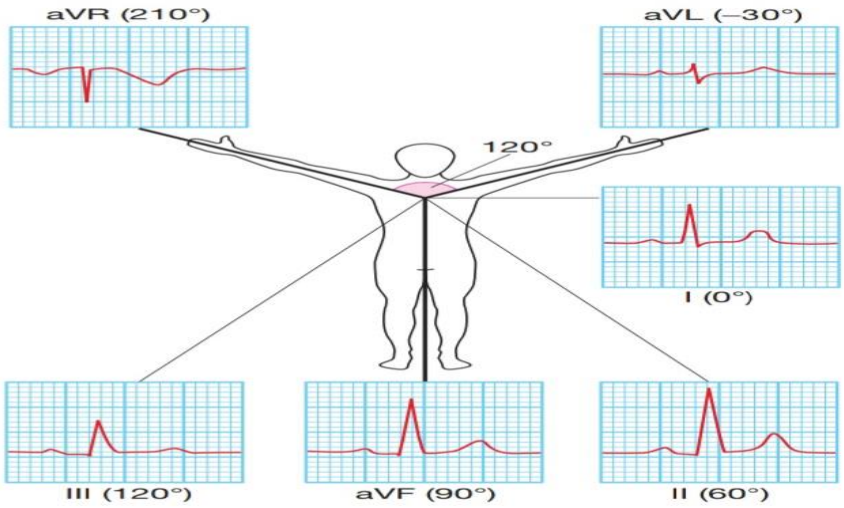
Figure(3). Normal electrocardiogram.[14]

*The 12-lead ECG

The 12-lead ECG is generated by ten electrodes attached to the skin. Six electrodes are attached to the chest, and one electrode to each limb. Furthermore, the electrodes on the right arm, left arm, and left leg are connected to a central terminal, which acts as an additional virtual electrode in the center of the chest (the electrode in right leg acts as an earthing electrode). The 12-leads ECG are recordings made from pairs or sets of these electrodes. They are divided into three categories: dipole limb leads, augmented voltage limb leads, and unipole chest leads.

The electrical activity between a limb electrode and a modified central terminal is recorded by these leads. Lead aVL, for example, records the signal between the left arm (+ve) and a central (-ve) terminal formed by connecting the electrodes of the right arm and left leg. Likewise, augmented signals are obtained from the right arm (aVR) and the left leg (aVF). These leads, which are 120° apart, also record electrical activity in the frontal plane. Thus, lead aVF looks at activity along the axis +90°, lead aVL looks at activity along the axis 30°, and so on. When depolarisation moves towards a positive electrode, the ECG shows a positive deflection; when depolarisation moves in the opposite direction, the ECG shows a negative deflection.

When the vector is perpendicular to a lead, the depolarisation in that lead is equal in both negative and positive directions (isoelectric). In (Fig.4), the QRS complex is isoelectric in aVL, negative in aVR, and strongly positive in lead II; the main vector or axis of depolarisation is thus 60°. The normal cardiac axis ranges from 30° to +90°.



Figure(4). Normal appearance of the ECG from different leads in the frontal plane. [14]

V1–V6 chest leads are derived from electrodes placed on the anterior and lateral left side of the chest, over the heart. Each lead records the signal that travels between the corresponding positive chest electrode and the central terminal (negative). Leads V1 and V2 are located approximately over the RV, V3 and V4 are located over the interventricular septum, and V5 and V6 are located over the LV. (Fig.5).

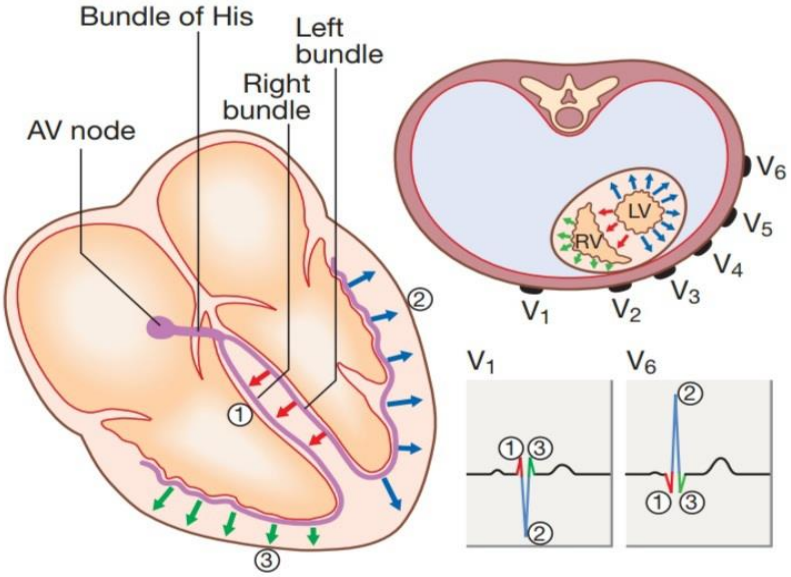


Figure (5). The sequence of activation of the ventricles. [14]

The LV has the most muscle mass and contributes the most to the QRS complex. The QRS complex's shape varies across the chest leads. The interventricular septum depolarizes first and moves from left to right, resulting in a small initial negative deflection in lead V6 (Q wave) and an initial positive deflection in lead V1 (R wave). The activation of the LV body in the second phase of depolarisation results in a significant positive deflection or R wave in V6 (with reciprocal changes in V1). The RV is involved in the third and final phase, which results in a small negative deflection or S wave in V6.[14]

*Risks

The ECG is a painless, non-invasive test with no major risks or complications. An allergic reaction or skin sensitivity to the adhesive gel can occur, but it usually resolves as soon as the electrode patches are removed and does not require any treatment. Artifacts and distortions pose serious diagnostic difficulties and may lead to inaccurate interpretation of the ECGs that may probably result in an adverse therapeutic intervention. The inadvertent misplacement of ECG leads may lead to misdiagnosis.[15]

*Exercise electrocardiogram

In exercise or stress electrocardiography a 12-lead ECG is recorded during exercise on a bicycle ergometer or treadmill. It is similar to a resting ECG, except that the limb electrodes are placed on the hips and shoulders instead of the ankles and wrists. The Bruce Protocol is the most widely used. During an exercise electrocardiogram, blood pressure is recorded and symptoms are assessed. False -ve results can occur. This is especially true in low-risk individuals, such as asymptomatic young or middle-aged women, in which abnormal response is more likely to represent a false +ve than a true +ve test. Stress testing is contraindicated in patient with sever hypertension, decompensated heart failure and acute coronary syndrome.[14]

Indications
• To confirm the diagnosis of angina • To evaluate stable angina • To assess prognosis following myocardial infarction • To assess outcome after coronary revascularisation, e.g. coronary angioplasty • To diagnose and evaluate the treatment of exercise-induced arrhythmias
High-risk findings
• Low threshold for ischaemia (within stage 1 or 2 of the Bruce Protocol) • Fall in blood pressure on exercise • Widespread, marked or prolonged ischaemic ECG changes • Exercise-induced arrhythmia

Table(1). Indications and high-risk findings of exercise ECG. [14]

*The effect of exercise on the electrocardiogram in healthy subjects

Measurement of directions and magnitudes of time-normalized P, QRS, ST vectors, and other ECG parameters during and after multistage exercise was done. A single representative beat was obtained from each stage using selective averaging on a digital computer system. This beat was used to take measurements. During exercise the interval between the spatial maximum of P wave and onset of QRS complex reduced, while the magnitude of the P wave increased. The P vectors' directions remain unchanged. This pattern is associated with electrocardiographic manifestations of predominant right atrial overload. There were no significant changes in the QRS duration. The maximum QRS vectors' magnitude and spatial orientation remained constant as well. The time between onset of QRS and maximum spatial magnitude of the T wave was shortened. The terminal ST and QRS vectors gradually shifted to the right and superiorly.

During exercise, the magnitude of T decreased. The P and T magnitudes increased significantly in the first minute of the recovery period. Following that, all measurements gradually returned to their resting levels. Although age did not contribute to the variance of the ECG measurements, some ST-segment measurements could be significantly reduced by relating them to heart rate using linear regression equations (P less than or equal to 0.05). As a result, it is expected that when heart rate dependent normal limits for ST-segment measurements are used, the sensitivity of the exercise ECG for detecting ischemic heart disease will be increased.[16]

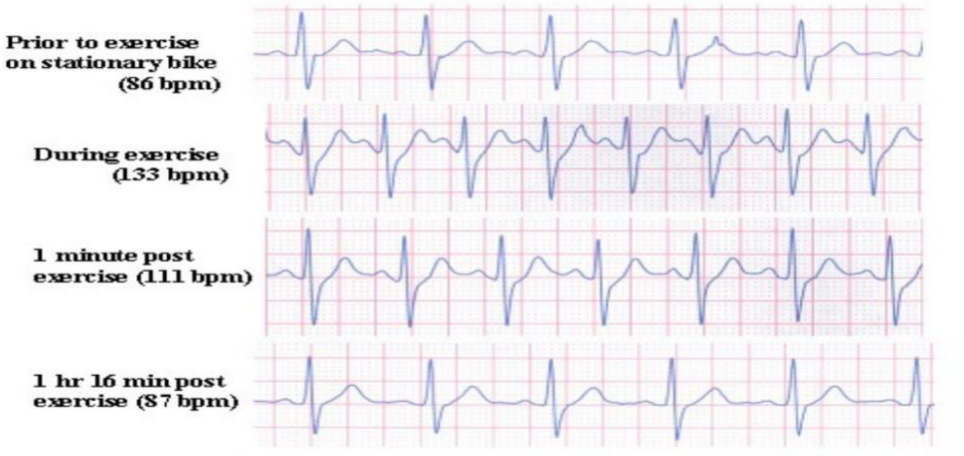


Figure (6). ECG changes after exercise ECG in healthy subjects .

***The effect of exercise on the electrocardiogram in patient with angina pectoris**

Angina is the commonest symptom of ischemic heart disease, which is a leading cause of death and morbidity worldwide. Chest pain can be caused by both cardiac and non-cardiac causes, and a thorough history and physical examination are essential in distinguishing these causes and identifying patients with ACS. Angina is one of the symptoms of acute coronary syndrome and is further classified as stable or unstable angina. Unstable angina or symptoms that occur at rest necessitate more prompt evaluation and treatment. The occurrence of symptoms with exertion only is defined as stable angina.[17] The first-line investigation is an exercise electrocardiogram, which should be performed using a bicycle ergometer or a standard treadmill protocol while monitoring the patient's pulse, blood pressure, and general condition. Ischemia is defined by a planar or downsloping ST segment depression of 1 mm or more. (Fig. 7). Up-ST depression is less specific; it frequently occurs in healthy people, and false-positive results can occur with left ventricular hypertrophy, digoxin therapy, WPW syndrome, and bundle branch block. In combination with other clinical features, the amount of exercise tolerated and the extent of ST segment change can be useful in identifying high-risk individuals with severe coronary disease. However, in a significant proportion of patients with coronary artery disease, exercise testing may be normal, or it may be inconclusive because an adequate HR cannot be achieved due to reduced mobility or other non-cardiac problems. As a result, if clinical suspicion is high and the exercise electrocardiogram is inconclusive or normal, additional imaging with stress echocardiography or myocardial perfusion scanning is recommended. A perfusion defect that is present during stress but not at rest indicates reversible myocardial ischaemia, whereas a persistent perfusion defect that is present during both phases of the study is usually indicative of a previous myocardial infarction.[14]

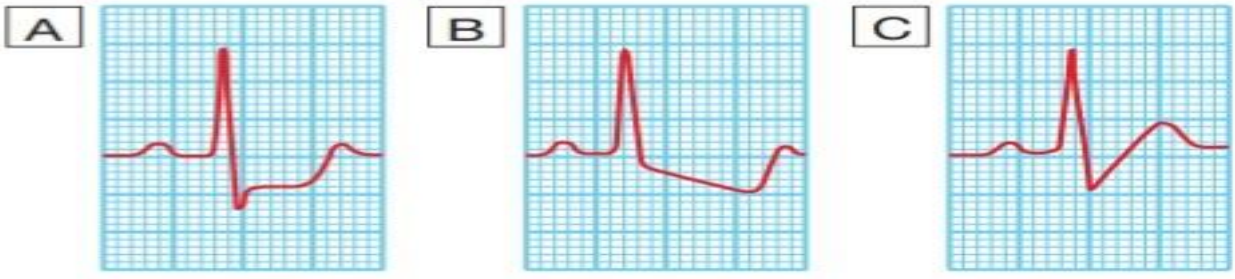
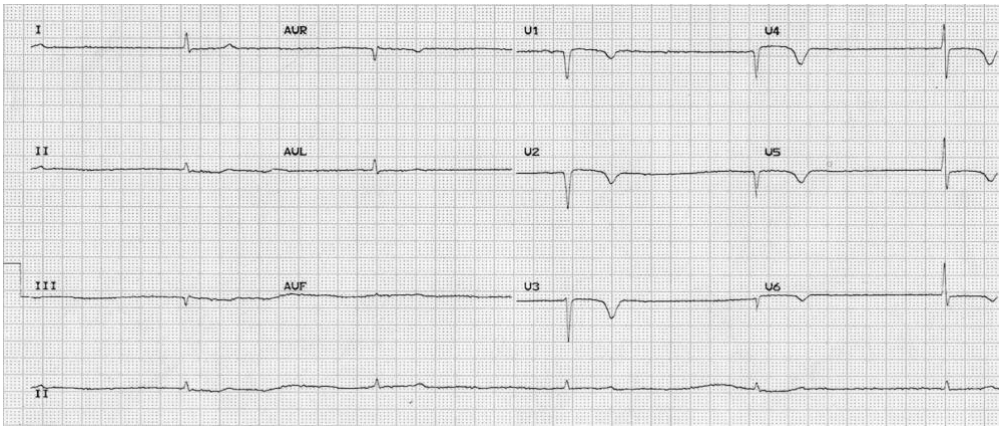


Figure (7). Forms of exercise-induced ST depression. (A) Planar ST depression is usually indicative of myocardial ischaemia. (B) Down-sloping depression also usually indicates myocardial ischaemia.(C) Up-sloping depression may be a normal finding. [14]

*Electrocardiographic abnormalities in hypothyroidism before and after exercise

Hypothyroidism is a common pathological condition characterized by deficiency of thyroid hormone. If left untreated, it can cause serious health problems and, in the worst-case scenario, death. Because of the wide range of clinical manifestations and the general lack of symptom specificity, the definition of hypothyroidism is predominately biochemical. TSH concentrations above the reference range and free thyroxine concentrations below the reference range indicate overt or clinical primary hypothyroidism. Mild or subclinical hypothyroidism is defined by thyroid stimulating hormone levels above the reference range and free thyroxine levels within the normal range, and is commonly regarded as a sign of early thyroid failure.[18]

After exercise there was a significant acceleration of the HR (+ 23.39/min, p less than 0.001), shortening of the PR interval (-0.66 csec, p less than 0.02) and T wave elevation (+ 0.40 mm, p less than 0.001). ST segment changes were not recorded in any case. Replacement treatment in 7 cases resulted in a great change in the resting HR (+ 11.86/min. p less than 0.025), PR interval (-3.28 mm, $p < 0.025$) and T wave height (+ 2.50 mm, p less than 0.01). These findings suggest that exercise may be used in the differentiation between coronary heart disease and hypothyroidism. An increase in cardiac energy demands during exercise may be the cause for some of the ECG changes observed on exertion. Following exercise, there was a significant increase in heart rate (+ 23.39/min, p less than 0.001), a decrease in PR interval (-0.66 csec, p less than 0.02), and an increase in T wave elevation (+ 0.40 mm, p less than 0.001). Changes in the ST segment were not observed in any of the cases. In seven cases, replacement treatment resulted in a great change in resting HR (+ 11.86/min, p less than 0.025), PR interval (-3.28 mm, p less than 0.025), and T wave height (+ 2.50, p less than 0.01). These findings imply that exercise could be used to distinguish between hypothyroidism and coronary heart disease.[19]



Figure(8). Electrocardiographic changes in hypothyroidism.

*The effect of exercise on the electrocardiogram in patient with brugada syndrome

Brugada syndrome is genetic disease that predisposes patients to fatal cardiac arrhythmias, characterized by the electrocardiogram findings of RBBB and ST-segment elevations in the right precordial leads (V1-V3).[20]

A 12-lead electrocardiogram is significant to both diagnose and decide management options of Brugada syndrome. Three different electrocardiogram patterns have been described in Brugada syndrome patients: coved ST elevations greater than two mm accompanied with inverted T wave (type I), saddleback-shaped ST elevation greater than two mm (type II), and saddle-back shaped ST elevations less than two mm (type III). Additionally, patients with a normal electrocardiogram and high-risk factors may require drug challenge test to reveal the typical electrocardiogram findings of ST elevations in the precordial leads V1 to V3. These high-risk factors that may require provocative drug testings include having a family history of sudden cardiac death, family history of Brugada syndrome, symptoms consistent with Brugada syndrome in the setting of questionable electrocardiogram abnormalities.[21]

166 Brugada patients are undergoing exercise testing. When exercise testing was performed on Brugada patients, the average age was 46 years (range, 28–72 years). 98 percent of Brugada patients were men. Prior to exercise testing, 24 patients had a history of ventricular fibrillation (VF), 52 had a history of syncope alone, and 6 had a history of palpitations, while the remaining 86 were asymptomatic. Exercise testing resulted in electrocardiogram changes in 101 of 166 (61%) patients, while no changes were seen in 65. (39 percent).

The most common ECG change associated with exercise testing was an increase or augmentation of ST segment elevation (ST augmentation). The ST augmentation was observed in 95 (57%) of the 166 Brugada patients. In 93 Brugada patients, ST augmentation happened during early recovery after exercise, whereas 2 patients developed ST augmentation during the effort phase of exercise. At baseline, there was no significant ST elevation in leads V1 through V3, but exercise revealed typical coved type 1 ECG changes, leading to the diagnosis. In three patients with known Brugada, the ECG pattern changed with exercise from a saddle shaped to a coved type Brugada pattern. With exercise, three patients developed ventricular arrhythmias: two developed ventricular tachycardia and one developed multiple ventricular extrasystoles. All three arrhythmias occurred during the early stages of recovery following exercise testing and resolved spontaneously.[22]

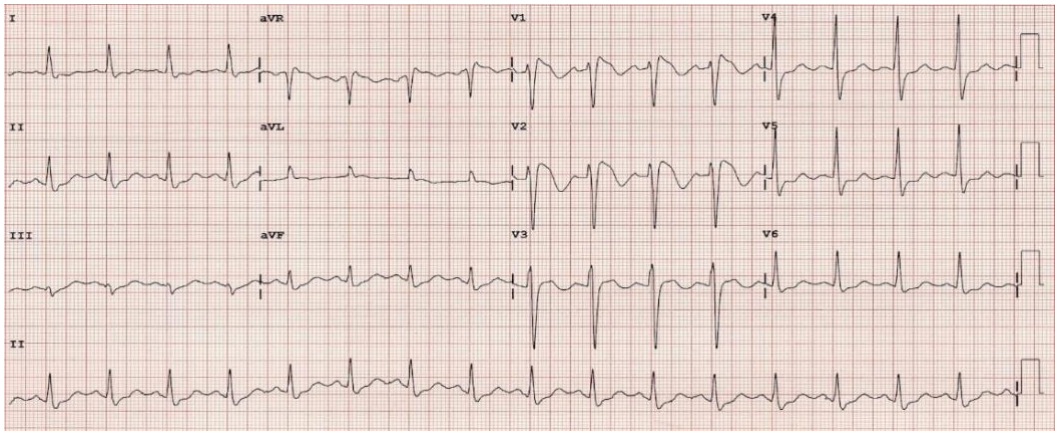


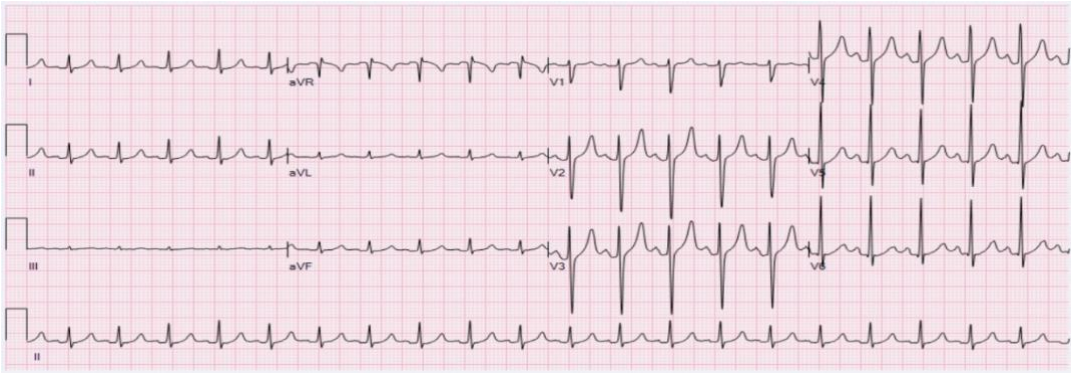
Figure (9). Electrocardiographic pattern in brugada syndrome[..]

*Electrocardiographic changes after exercise ECG in patients with chronic anemia

Anemia is a condition in which the hemoglobin (Hb) concentration and/or red blood cell (RBC) numbers are lower than the normal and insufficient to meet the physiological needs of an individual.[23]

There was a strong negative correlation between Hb level and tachycardia and ECG changes; as the Hb level decreased there was more percentage of patients having tachycardia and ECG changes .

The study is aimed to determine the incidence of certain electrocardiographic changes in anaemic patient at rest and after exercise ECG. 30 patients with anaemia, normal x ray findings and free of cardiorespiratory diseases. The average haemoglobin value in the studied group was 85.6 g/L. The subjects underwent submaximal ergometric test. The following ECG parameters were monitored: P wave, PR interval, R amplitude, R difference, ST segment depression, T wave, QT interval and QTc interval. The ECG findings revealed ST segment depression at rest in one patient .During the stress test, ECG findings revealed ST segment depression in 10 patients, which proved to be statistically significant. Negative T wave at rest was recorded in no patient of the group, while after the stress test ECG findings revealed negative T wave in 3 patients. Prolonged QT interval was recorded in 8 patients (this finding was considered as statistically significant). The increased R difference was statistically significant. There were no increased QTc differences in the group.[24]



Figure(10). Electrocardiographic pattern in patient with anemia.

*Results and discussion

Alterations in an electrocardiogram can be a sign of many heart-related conditions. An exercise electrocardiogram is done to assess the heart's response to stress or exercise. The main findings of this study are differ in each medical condition.

In patient with stable angina the stress test is performed to confirm the diagnosis of coronary artery disease which appear normal at rest and induced by exercise, down-sloping ST segment depression of 1 millimeter or greater is indicative of ischaemia.

At rest patients with overt hypothyroidism show several electrocardiographic (ECG) changes including sinus bradycardia, low amplitude QRS complexes, QT interval prolongation, and alterations in T wave morphology, Following exercise there was a significant acceleration of the heart rate, shortening of the PR interval and T wave elevation. ST segment changes were not observed.

Patients with brugada syndrome at rest have multiple ECG patterns which characterized by incomplete RBBB and ST elevations in the anterior precordial leads.

The most frequent electrocardiogram change with exercise testing was increasing or augmentation of the ST-segment elevation (ST augmentation). The ST augmentation occurred during early recovery after exercise in most patient with Brugada syndrome, whereas only few patients developed ST augmentation during the effort phase of exercise.

At rest most Patients with chronic anemia were presented with sinus tachycardia and several ECG changes.

After exercise several ECG changes were recorded [ST segment depression, T wave inversion , prolonged QT interval, increase R difference].

*Conclusion

Exercise ECG test provides a cost-effective, non-invasive, rapid and reliable prediction of coronary artery disease and cardiac death under certain circumstances. ECG stress test interpretation should include a combination of history, clinical response to stress, and ECG findings.

Physiological testing remains the gold standard in patients with established or suspected coronary disease, particularly in the prognostic evaluation of the disease. Exercise test testing and myocardial perfusion scintigraphy appear to be very accurate techniques in this context. Indeed, as seen in patients with either epicardial or microvascular coronary artery disease, the presence and extent of inducible myocardial ischaemia have a strong correlation with clinical outcome and should thus be considered as the most important factors for closely monitoring these patients.

In fact, anatomic evaluation of obstructive stenoses does not determine the haemodynamic significance of the lesions observed.

In conclusion, functional testing is still the most helpful tool for risk stratification in both macrovascular and microvascular coronary disease. In the near future, a combined anatomic-physiological approach using recent technological advances could become the best diagnostic/prognostic tool.

Hypothyroidism is a risk factor for ischemic heart disease, and exercise stress testing can identify occult coronary artery disease. Screening with a treadmill stress test should be performed, especially in those who have had hypothyroidism for a long time and have chest pain, breathlessness, and/or non-specific ST-T changes in their resting ECG, to detect an occult coronary artery. Patients with hypothyroidism who have a positive stress test and are symptomatic should have coronary artery revascularization therapy.

The findings that exercise can worsen the ST abnormalities in Brugada syndrome and cause ventricular arrhythmias, as well as the possibility that increased parasympathetic tone is both a risk factor in Brugada and an effect of exercise training, suggest that patients with Brugada syndrome should avoid vigorous exercise and exercise training until further research confirms or disproves this.

To avoid misdiagnosis, ECG changes can be used to support anaemia diagnosis in critical care, and anaemia correction can result in dramatic clinical and ECG recovery.

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