Cardiac Diagnostic Methods in Coronary Artery Disease: Electrocardiogram, "2-Step" Exercise Test and Ballistocardiogram

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The clinical importance and necessity of dependable cardiac diagnostic and function tests are emphasized by the outstanding fact that cardiovascular disease is the leading cause of death in the country today. However, the time honored methods of complete history, adequate physical examination, chest fluoroscopy and roentgenogram will never be replaced in value by the other available tests of heart function. The latter serve as corroborative laboratory aids for diagnosis and prognosis and in this regard, they play a vital role in the final clinical impression of the cardiac status.

Electrocardiography

Since the introduction of an accurate recording apparatus, the electrocardiograph has assumed increasing importance daily in the routine diagnosis of coronary artery disease.

Technique: Although the present electrocardiographic recording apparatuses leave much to be desired insofar as high frequency response is concerned, the customary amplifier type or string galvanometers yield records of sufficient fidelity for routine clinical use. All records should be accompanied by the standardization utilized, that is, 1 milli-Volt = 1 centimeter deflection for routine tracings. At present 12 lead records are recommended routinely: the three standard leads (I, II and III), the three augmented unipolar limb leads (aVR, aVL and aVF); and the six unipolar precordial chest leads (V₁ through V₆). Although less than the 12 mentioned are recorded routinely in many cardiac laboratories, instances of coronary disease in which abnormalities occur in only one lead are sufficiently common to preclude such abbreviations of technique. Moreover, situations such as high lateral myocardial infarction, may require even additional chest exploration for the detection of the cardiographic alteration.

The use of CR, CL or CF chest leads routinely as opposed to unipolar V leads introduces the valid objection of undue influence of the remote extremity electrode on the exploring chest piece. Current argument in favor of CF over V chest leads cannot be supported on theoretical grounds and any diagnostic advantage in an individual case may be considered merely fortuitous. On the other hand, the apparent advantage of unipolar extremity leads such as aVF in the diagnosis of posterior (diaphragmatic) myocardial infarction has been questioned by many workers.

Somatic tremor may usually be readily eliminated, but in some cases, as in Parkinsonism, may produce a regular undulation of the baseline.
which may be mistaken for auricular flutter. Alternating current interference should be eliminated by proper grounding.

**Interpretation:** The criteria for normality and abnormality of electrocardiographic tracings as regards coronary artery disease are generally universally accepted, although individual interpretations may vary. Unfortunately, normal individuals as well as those with anxiety states may present abnormal resting electrocardiographic tracings. Ergotamine and more recently, dihydroergocornine, have been utilized in the differentiation of such abnormal resting electrocardiographic tracings in functional heart disturbance as compared with organic coronary artery disease, the record returning to normal during exhibition of these drugs in the former condition.

Interpretation of electrocardiographic records as regards coronary disease without adequate knowledge of the age and clinical status of the patient is fraught with danger. Refusal to render a reading of tracings without this information is actually entirely justifiable. For example, the cardiac rotation and displacement with pulmonary collapse may result in electrocardiographic “abnormalities” in the absence of cardiac involvement.

**Specificity:** The Q waves of myocardial infarction represent the truly specific alterations of the electrocardiogram diagnostic of complete coronary artery occlusion. Although the appearance of significant Q waves may be delayed for several days or longer after acute coronary occlusion with through and through myocardial infarction, they usually remain permanently as the indicator of previous severe myocardial damage. With subsequent episodes of acute coronary occlusion, Q waves may appear in other leads or become deeper and/or wider, if already present. Q waves are usually considered significant only when they represent 25 per cent or more of the amplitude of the R wave or when they are 0.04 second or longer in duration. It should be remembered that a deep Q or QS deflection is a normal finding in lead aVR and that myocardial infarction may be reflected in this lead by the appearance of an early R wave! Even in the absence of significant Q waves, anterior wall myocardial infarction may be diagnosed by an alteration of the normal increment of the amplitude of the R wave as one proceeds from V₁ through to lead V₄ on the chest wall. In some instances, after recovery from acute coronary occlusion, the Q waves may become smaller and some records may lose the Q wave entirely and become normal.

RS-T segment deviations and T wave alterations are not specific for coronary artery disease. Unfortunately, these abnormalities may be associated with many other disease states such as rheumatic heart disease, pericarditis of any etiology, cardiac hypertrophy of any cause, pulmonary embolization, etc. Moreover, electrolyte imbalance (potassium, calcium) and even drinking of ice water may produce electrocardiographic changes in the RS-T segment and/or T waves indistinguishable from those associated with organic coronary artery disease. It is important to emphasize the difference between the electrocardiographic pattern of acute coronary
insufficiency and that of acute coronary occlusion. In the former there is noted typically RS-T segment depression and T wave inversion in all leads without the appearance of Q waves except aVR where one finds RS-T segment elevation and upright T waves. These findings are related to the subendocardial ischemia of coronary insufficiency. On the other hand in acute coronary occlusion with myocardial infarction, Q waves are typical and in leads with significant Q waves the RS-T segment is usually elevated and later T wave inversions appear. In infarction of the posterior wall of the myocardium (diaphragmatic) one may note tall pointed T waves in the right chest V leads.

Bundle branch block, intermittent or permanent, left or right, complete or incomplete, may occur in the presence of coronary artery disease. These patterns may obscure the appearance of significant Q waves with the onset of acute coronary occlusion—especially anterior wall myocardial infarction in a patient with left bundle branch block. However, it should be noted that such block patterns may be functional, positional, respiratory or congenital.

In coronary artery disease, the electrocardiogram may disclose tall, wide P waves, prolongation of the P-R interval, incomplete or complete A-V block, inverted u waves, premature beats and any other arrhythmia. Again, none of the alterations are specific for coronary disease. The Wolff-Parkinson-White pattern may be found in normal individuals as well as those with organic heart disease.

**Diagnostic Value:** The electrocardiogram at rest has been found to be entirely normal in from 25 to 60 per cent of patients with organic coronary artery disease. Therefore, early in the disease one may expect a normal tracing in a large number of individuals and if necessary, one must rely on other cardiac diagnostic tests. Later on in the progress of the disease, the electrocardiogram is more apt to be abnormal and then of diagnostic value in a positive sense. It must be reemphasized that a normal or abnormal electrocardiographic tracing must be interpreted in the light of the entire clinical picture to be of full value. Moreover, when the latter is combined with serial tracings, obscure states may often be resolved correctly and thus prognostic value may be obtained in the resting electrocardiogram.

The absolute necessity for more dependable methods for the diagnosis of coronary artery disease has led to the increasing popularity of the following tests of cardiac function—the "2-step" exercise electrocardiogram and the ballistocardiogram.

"2-Step" Exercise Electrocardiogram

It has been found that in 25 to 60 per cent of patients with coronary artery disease, the results of all routine investigations may be normal—physical examination, cardiac fluoroscopy, and chest teleroentgenogram. Following the introduction of the "2-step" exercise procedure in 1929, Maeter later applied the electrocardiographic changes following standard exercise as the test for coronary insufficiency.
Technique: After routine examination, the “2-step” test is performed only if the 12 lead resting electrocardiogram is normal. The patient walks over the “2-step” stairs with the electrodes left in place. Each step is nine inches (22.9 cm.) high. Routinely standard leads 1, 2, and 3 and precordial lead, V₄ or V₅ (with the tallest, widest R wave) are taken. More recently the four leads recorded are standard lead 2 and precordial leads V₃, V₄ and V₅. In the single test, the required number of ascents (complete trips over the steps in one direction) is determined from a table based upon sex, age and weight. The single test is performed in one-and-one-half minutes and the patient then returns to his original position, sitting or recumbent. The electrocardiogram (4 leads) is recorded immediately, two minutes and six minutes after completion of the exercise. In order to avoid dizziness the direction of the patient is changed after the completion of each trip; that is, he turns toward the examiner each time. In the event that the single test is normal, then a minimum of one hour later the double “2-step” is performed. The latter is twice the number of standard trips in three minutes and is advised only if the single “2-step” is normal, for reasons of safety. The importance of the double exercise is borne out by the fact that one-third of patients with abnormal double tests presented normal single tests.

Interpretation: Criteria for abnormal single and/or double “2-step” tests include: (1) Depression of the RS-T segment greater than $\frac{1}{2}$ mm. below the isoelectric (P-R) level; (2) Complete or partial inversion of a T-wave (except in lead 3); or (3) transient arrhythmias, conduction defects, or large Q waves. These alterations are identical with the electrocardiographic changes during spontaneous episodes of angina pectoris. The most sensitive leads for this test are the precordial (V₄ or V₅). Tracings are repeated beyond six minutes if necessary, until the record returns to the normal control. These electrocardiographic alterations are independent of the appearance of chest pain or pressure and the latter is not a criterion for a positive test. The “2-step” exercise is contraindicated if heart failure, cardiac enlargement or an abnormal resting electrocardiogram is found. Food or exercise within one hour, tobacco, digitalis and nitroglycerin all influence the result of the test.

Specificity: Abnormal “2-step” exercise electrocardiograms, single or double, present definite evidence of coronary insufficiency on effort. It must be emphasized that abnormal tests are not specific for coronary artery disease since other organic or functional states may be the underlying cause (rheumatic, luetic or congenital heart disease or severe anemia, for example). On the other hand the “2-step” test may be abnormal in from 6 to 8 per cent of normal people and also in patients with neurocirculatory asthenia or anxiety states. Differentiation between such functional states and true organic heart involvement may be made usually on clinical grounds alone. However, we have found dihydroergocornine (DHO-180), a “sympatholytic” agent, of value in this regard.

Diagnostic Value: The value of the “2-step” exercise test has been corroborated by a five year follow-up study of hundreds of patients. If both
the single and double “2-step” tests are normal, a diagnosis of coronary insufficiency and hence, coronary artery disease, is practically (but not absolutely) excluded. Thus, the value of the “2-step” test in the negative sense is inestimable. On the other hand, in patients with normal resting electrocardiograms, an abnormal single or double “2-step” test presents objective evidence of coronary insufficiency. The decision of a final label of coronary artery disease rests with the examining physician after correlation of the abnormal results of the exercise with the clinical status of the patient.

Ballistocardiography

In 1949 with the introduction of the direct body recording technique by Dock and Taubman, the ballistocardiograph became available generally as a practical cardiac function test. The ballistocardiogram is a record of the motion of the body induced by the contraction of the heart and the surge of blood into the arterial tree during each cardiac cycle. We have investigated the ballistocardiograph in over 2,000 patients during the past four years and have utilized a modified Dock type instrument, the Pordy dual ballistocardiograph for recording both photoelectric (displacement) and electromagnetic (velocity) tracings with a single setting. A report of the accuracy of this apparatus as checked mechanically with linear reciprocating motion by Dr. Sergei Feitelberg is in progress.

Technique: The patient lies supine on a fixed, immobile table. A cross-bar placed on the shins transmits the longitudinal body motions (without a hinge) by cutting light falling on the photo-cell and/or by altering an electromagnetic field. The record is taken on the customary electrocardiographic machine by direct attachment to the lead 1 electrodes. Whenever time reference is desired, simultaneous electrocardiograms and ballistocardiograms may be recorded simply, even on the routine single channel electrocardiographs. The ballistocardiogram is recorded during quiet respiration and then deep inspiration and finally deep expiration.

Interpretation: Ballistocardiograms, like electrocardiograms, may be read by direct inspection of the record. The normal ballistocardiogram is of a W-shaped appearance, with the base-line one which bisects the waves. By convention, headward motion of the body is represented as an upward deflection on the record and vice versa. The component waves are labeled in alphabetical order according to Starr, commencing with the letter “H.” This represents the first headward motion with each cardiac cycle and is related to the apical thrust. The I-wave represents the recoil of the body to ejection in early systole. The most prominent headward wave is the J-wave and this results from impact on the aortic arch and acceleration of blood in the aorta. The K-wave is the most prominent footward deflection and is related to deceleration in the descending aorta. L, M, N and O, and so on, are the diastolic after vibrations or actually forced thrusts.

The records are interpreted on the qualitative appearance of the component waves of the ballistocardiogram and we have not attempted their use quantitatively as a measure of cardiac output. In normal persons,
there is a respiratory variation in the amplitude of the complexes, being of greater amplitude in inspiration than in expiration. Criteria for abnormality include: (1) diminished or absent I-waves; (2) exaggeration of the normal respiratory variation so that the amplitude of the waves during expiration is 50 per cent or less than during inspiration; (3) slurring or notching of I, J, or K-waves; (4) early “M” pattern—prominent H-waves; (5) late “M” pattern—late, deeply notched J-waves; (6) prominent diastolic waves (L, M, N, O, and so on); (7) deep, wide or absent K-waves; or (8) low amplitude or totally bizarre complexes. Any one record may display one alteration alone or various combinations. Moreover, abnormal waves may be detected in only one phase of respiration. For example, in early coronary disease alterations may appear in the complexes only during the expiratory phase.

**Specificity:** Like the resting and “2-step” exercise electrocardiogram, there is no ballistocardiographic pattern specific for coronary artery disease. The factor of age plays an important role in interpretation. Under the age of 50 one would expect to find a normal ballistocardiogram almost routinely. Therefore, an abnormal tracing in a coronary disease suspect under 50 is of great significance diagnostically, since thereafter the record may be altered by physiological aging processes. On the other hand a normal ballistocardiogram in a patient over 50 would correlate well with a normal cardiovascular tree. It must be pointed out that in patients with coronary artery disease who undergo complete functional recovery, the ballistocardiogram and the resting as well as exercise electrocardiogram may return to normal.

**Diagnostic Value:** Ballistocardiography has its greatest application in the diagnosis of coronary artery disease. In patients with angina pectoris and abnormal resting electrocardiograms, 93 per cent presented abnormal ballistocardiograms as well. Moreover, in 85 per cent of patients with angina pectoris, normal resting electrocardiograms but abnormal “2-step” exercise tests, the ballistocardiograms at rest were abnormal. The use of standard exercise ballistocardiograms increased this figure to 90 per cent. In early cases of coronary artery disease, cardiac ejection may be altered only following exertion. Therefore, the ballistocardiogram should be recorded after standard exercise if the resting record is normal. A close correlation was found between abnormal “2-step” exercise tests and abnormal resting ballistocardiograms. Both should be employed routinely in the detection of coronary artery disease since one records electrical and the other mechanical events.

The high percentage of abnormal ballistocardiograms in hypertensive patients limits its value somewhat in the diagnosis of coronary artery disease. In patients with acute myocardial infarction, the ballistocardiogram becomes abnormal and may return to normal (in 19 per cent) usually paralleling functional recovery. Thus the value extends to prognosis in coronary disease patients. In the diagnosis of coronary disease, the ballistocardiogram offers a simple means of early detection with the advantage of lack of any danger to the patient. The use of the tobacco
ballistocardiographic test may enhance the diagnostic value of this procedure in coronary disease.

**Conclusion**

The clinical status and routine examination of the patient should be correlated with the results of a battery of tests—the electrocardiogram, the Master “2-step” exercise test and the ballistocardiogram—for the final, early and accurate diagnosis of coronary artery disease.

**SUMMARY**

1. The scope of the problem of the diagnosis of coronary artery disease is discussed.
2. The value and limitations of routine electrocardiography is outlined.
3. The Master “2-step” exercise test is described and the diagnostic value is stressed.
4. The ballistocardiogram is presented as a valuable means for early detection of coronary disease.

**RESUMEN**

1. Se discute el alcance del problema del diagnóstico de la afección de la arteria coronaria.
2. Se presenta el valor y las limitaciones de electrocardiografía de rutina.
3. El ejercicio “Master two step” se detalla y se subraya su valor diagnóstico.
4. Se presenta el balistocardiograma como un valioso medio para el descubrimiento temprano de la afección coronaria.

El estado clínico y el examen de rutina del enfermo deben ser correlativos con el resultado de las pruebas en batería o grupe: el electrocardiograma, el ejercicio “Master two step” y el balistocardiograma, a fin de hacer un diagnóstico final y exacto de la enfermedad coronaria.

**RESUME**

1) L'auteur met en discussion la question du diagnostic de l'atteinte de l'artère coronaire.
2) Il insiste sur la valeur et sur les limites de l'électrocardiogramme habituel.
3) Il précise la valeur du test essentiel de l'exercice dit "des deux pas" et son importance au point de vue du diagnostic.
4) Il considère le balistocardiogramme comme un moyen valable pour découvrir précocément l'atteinte coronarienne.

L'état clinique et l'examen systématique du malade doivent être conjugués à ce que donne toute une série de tests : électrocardiogramme, exercice "des deux pas," ballistocardiogramme. Ainsi le diagnostic des maladies coronariennes pourra être définitif, précoce et précis.
REFERENCES