Exercise Electrocardiography

Practical Approach

Second Edition

Edward K. Chung, M.D.

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Edited by

Edward K. Chung, M.D.

Professor of Medicine
Jefferson Medical College of
Thomas Jefferson University
Director of the Heart Station and
Attending Physician (Cardiologist)
Thomas Jefferson University Hospital
Philadelphia, Pennsylvania 19107

Fellow, American College of Cardiology
Former Governor for West Virginia, American College of Cardiology
Fellow, American College of Physicians
Honorary Fellow, Philippine College of Cardiology and
Philippine Heart Association
Member, American Federation for Clinical Research
Member, American Heart Association
Member, American Medical Association
Member, Pennsylvania Medical Society
Member, Philadelphia County Medical Society

Editorial Board Member for *Cardiology,*
The Journal of Electrocardiology, Heart and Lung, Primary Cardiology
and *Hospital Physician*

WILLIAMS & WILKINS
Baltimore/London

Made in the United States of America

First Edition, 1979
Reprinted 1980
Second Edition, 1983
Reprinted, 1984

Library of Congress Cataloging in Publication Data

Main entry under title:

Exercise electrocardiography.

Includes index.
1. Electrocardiography. 2. Exercise tests. 3. Heart function tests. I. Chung, Edward K. [DNLM: 1. Electrocardiography. 2. Exercise test. WG 140 E96]
RC683.5.E5E95 1983 616.1'207547 82-21734
ISBN 0-683-01571-0

Composed and printed at the
Waverly Press, Inc.
Mt. Royal and Guilford Aves.
Baltimore, MD 21202, U.S.A.

To My Wife, Lisa,
and
To My Children,
Linda and Christopher

Preface to the Second Edition

Since the first edition of *Exercise Electrocardiography* was published in 1979, a significant development has been observed. Remarkable improvement has been made in the field of nuclear cardiology from a technical as well as a medical viewpoint. Thus, Chapter 17, "Myocardial Perfusion Imaging with Thallium-201," has been expanded in view of the markedly improved specificity of the diagnosis, especially when the exercise ECG test is difficult to interpret because of various reasons (e.g., preexisting ECG abnormalities such as left bundle branch block, left ventricular hypertrophy, etc.) and when the exercise ECG test result is equivocal.

A new chapter, "Exercise ECG Test in Patients with Recent Myocardial Infarction" (Chapter 7), is added because the exercise ECG test has proven to be an extremely valuable tool to assess various clinical parameters in patients with recent myocardial infarction. In addition, a chapter dealing with "Exercise ECG Test in Patients with Coronary Artery Spasm" (Chapter 8) is included in this book, because coronary artery spasm has become a well-established clinical entity which not uncommonly causes angina pectoris, and a fixed coronary stenosis often coexists with coronary artery spasm. Exercise ECG test has been shown to be a valuable tool in this entity.

A new chapter entitled "Exercise Training in Chronic Obstructive Pulmonary Diseases" is also included because the exercise ECG test is frequently performed among pulmonary patients.

Since the ambulatory ECG (Holter monitor ECG) is frequently performed in conjunction with the exercise ECG test in our practice, a new chapter entitled "Comparison of Ambulatory (Holter Monitor) Electrocardiography and Exercise ECG Test" (Chapter 15) is included.

Two new chapters entitled "Value of the Exercise ECG Test before Engaging in Any Exercise Program or Sport" (Chapter 19) and "Exercise Recommendations and Prescriptions for Cardiac Patients and Healthy Individuals" (Chapter 20) are added because numerous healthy individuals as well as cardiac patients engage in various exercise programs or sports, and the exercise ECG test is indispensable under these circumstances.

Lastly, a new chapter entitled "Computer Analysis of Exercise ECG Test" (Chapter 21) is also included in this book, because the interpretation of the exercise ECG test is assisted by computer analysis, at least in part, at many medical centers.

The intention and contents of the second edition of this book is essentially the same as those of the first edition—clinical, concise and practical. Thus, this book will provide all physicians with up-to-date materials related to the exercise ECG test.

I am grateful to all authors for their valuable contributions to this book, *Exercise Electrocardiography: Practical Approach, Second Edition.*

Edward K. Chung, M.D.

Preface to the First Edition

Exercise electrocardiography (the exercise ECG test or the stress ECG test) is clearly one of the most important and the most popular noninvasive diagnostic tests in the field of cardiovascular disease.

The primary purpose of exercise electrocardiography is to determine the nature and the etiology of chest pain. By doing so, the early diagnosis of coronary heart disease can be made by the exercise ECG test.

In addition, the efficacy of medical as well as surgical therapy for the cardiac patient can be assessed. Furthermore, the functional capacity of the cardiac patient can be evaluated by the exercise ECG test.

The aim of this book is to provide useful information regarding exercise electrocardiography for the diagnosis and management of cardiac patients. This book presents 17 chapters including Introductory Remarks on Exercise Electrocardiography, Master's Two-Step Test, Preparations and Precautions for the Exercise ECG Test, Methodology of the Exercise ECG Test: Technical Aspects, Problems Related to the Execise ECG Test, Effects of Drugs and Metabolic Abnormalities on the Exercise ECG Test, Indications of the Exercise ECG Tet, Contraindications of the Exercise ECG Test, Protocols for the Exercise ECG Test, Exercise ECG Test in Children, Physiologic versus Abnormal Responses to Exercise, Interpretation of the Exercise ECG Test, Exercise-induced Cardiac Arrhythmias, Myocardial Perfusion Imaging with Thallium 201: Correlation with Exercise Electrocardiography and Coronary Angiography, Value of the Exercise ECG Test for Screening Asymptomatic Subjects for Latent Coronary Artery Disease, Circulatory Adjustments to Exercise, and Complications of the Exercise ECG Test and Some Aspects of Medicolegal Problems.

The intention of this book is to describe every pertinent aspect of exercise electrocardiography, which is directly or indirectly related to the patient's care. The contents are intended to be clinical, concise and practical, so that this book will provide all physicians with up-to-date materials related to the exercise ECG test.

This book will be particularly valuable to all primary physicians, including family physicians, internists, cardiologists, cardiology fellows and medical residents. In addition, medical students, coronary care unit nurses and physicians in the field of rehabilitation medicine will obtain a great benefit by reading this book.

I am sincerely grateful to all authors for their valuable contributions to this book, *Exercise Electrocardiography: Practical Approach.* I also wish to thank my personal secretary, Miss Theresa McAnally, for her devoted and cheerful secretarial assistance. She has been most valuable

in handling correspondence to all contributors in addition to typing many of my chapters for this book. It has been my pleasure to share the work to complete this valuable book with the Staff of The Williams & Wilkins Company.

Lake Naomi,
Mt. Pocono, Pa.

Edward K. Chung, M.D.

Contributors

Bruce C. Berger, M.D., F.A.C.C.
Assistant Professor of Medicine
Nuclear Cardiologist
Jefferson Medical College of
Thomas Jefferson University
Philadelphia, Pennsylvania

Bernard R. Chaitman, M.D., F.A.C.C.
Associate Professor of Medicine
University of Montreal
Director of Non-Invasive Laboratory
Montreal Heart Institute
5000 East Belanger Street
Montreal, Quebec, Canada

Edward K. Chung, M.D., F.A.C.P., F.A.C.C.
Professor of Medicine
Jefferson Medical College of
Thomas Jefferson University
Director of the Heart Station
Thomas Jefferson University Hospital
Philadelphia, Pennsylvania

Lisa S. Chung, M.D.
Eastern Regional Medical Director
U. S. Postal Service
Philadelphia, Pennsylvania

William S. Frankl, M.D., F.A.C.P., F.A.C.C.
Professor of Medicine
Jefferson Medical College of
Thomas Jefferson University
Associate Director, Cardiology Division
Thomas Jefferson University Hospital
Philadelphia, Pennsylvania

Victor F. Froelicher, M.D., F.A.C.C., F.A.C.P.
Associate Professor of Medicine
University of California at San Diego
Director, Cardiac Rehabilitation and Exercise Testing
University of California at San Diego
San Diego, California

Patrick A. Gorman, M.D.
Associate Professor of Medicine
George Washington University Medical Center
Washington, D.C.

Ruth N. Harada, M.D.
Assistant Professor of Medicine
University of Colorado
Health Sciences Center
Denver, Colorado

Frederick W. James, M.D., F.A.C.C.
Professor of Pediatrics
Head, Exercise Laboratory
Children's Hospital
Elland and Bethesda Avenue
Cincinnati, Ohio

Thomas L. Petty, M.D., F.A.C.P.
Professor of Medicine
Head, Division of Pulmonary Sciences
University of Colorado
Health Sciences Center
Denver, Colorado

Marios Savvides, M.D.
Visiting Research Cardiologist
Concord Hospital
Sydney, Australia

Pierre Théroux, M.D., F.R.C.P., F.A.C.C.
Associate Professor of Medicine
University of Montreal School of Medicine
Chief, Coronary Care Unit, Montreal Heart Institute
Montreal, Quebec, Canada

David D. Waters, M.D., F.A.C.C., F.R.C.P.
Assistant Professor of Medicine
University of Montreal School of Medicine
Staff Cardiologist
Institut de Cardiologie de Montreal
Montreal, Quebec, Canada

Nanette K. Wenger, M.D., F.A.C.P., F.A.C.C.
Professor of Medicine (Cardiology)
Emory University School of Medicine
Director of Cardiac Clinics
Grady Memorial Hospital
Atlanta, Georgia

Contents

CHAPTER ONE

Introductory Remarks on Exercise Electrocardiography

EDWARD K. CHUNG, M.D., F.A.C.P., F.A.C.C.

GENERAL CONSIDERATIONS[1-9]

The exercise electrocardiography (stress ECG test or exercise ECG test) is one of the most important and valuable noninvasive diagnostic tests in the clinical evaluation and management of patients with suspected or known cardiovascular disease, particularly coronary artery disease. The exercise ECG test is also a very useful tool as a screening procedure for healthy individuals who are considered to be at possible risk of coronary heart disease. In addition, the exercise ECG test is highly recommended for healthy individuals as well as for cardiac patients before they engage in any exercise program or sport.

Initially, the Master's two-step test was very popular, but it has been gradually replaced by the treadmill exercise ECG test in the past decade, primarily because only insufficient exercise can be performed by the former. Namely, there will be a lack of sufficient sensitivity by the Master's test leading to an extremely high incidence of false negative tests. In the United States of America, the exercise electrocardiography is performed by a motor-driven treadmill in most medical institutions and many private offices of physicians. In European countries, however, the treadmill exercise ECG test is much less popular, and, instead, a bicycle ergometer is commonly used. The reason for this is probably that Europeans are more familiar with bicycle riding than are Americans. In addition, other forms of exercise ECG tests have been evaluated, such as induced-hypoxia, isometric exercise and atrial pacing. These exercise tests have not gained wide popularity, owing to difficulties in performance and standardization as well as a lack of sensitivity and specificity (sensitivity and specificity are discussed later in this chapter). At present, various multistage exercise protocols have been developed by different investigators for the exercise ECG test using either a motor-driven treadmill or an electrically-braked bicycle ergometer (see Chapter 10).

The exercise ECG test is primarily used for the assessment of the etiology of chest pain and for early detection of coronary heart disease. In addition, the exercise ECG test can provide valuable information in evaluating the functional capacity of the patients with coronary artery disease and in evaluating the efficacy of medical as well as surgical

therapy. Furthermore, the exercise ECG test is frequently performed in patients who have recovered from acute myocardial infarction, because the test result provides valuable information for assessing various clinical parameters (e.g., risk factors), especially for those with high risk categories (see Chapter 7).

HISTORICAL CONSIDERATIONS

As far as a history of the exercise electrocardiography is concerned, Dr. Arthur M. Master's original contribution is truly legendary, and he unquestionably deserves invaluable credit and recognition.[10, 11] Before the introduction of Master's two-step test in 1929,[10] the earliest recognition in the field of the exercise ECG test should be credited to Bousfield.[12] The S-T segment depression was recorded in the three standard leads during a spontaneous angina in 1918 by Bousfield for the first time.[12] Later, in 1928, Feil and Siegel[13] demonstrated that angina was accompanied by a prolonged period of the S-T segment depression. They used the term "positive response" when the S-T, T wave changes were produced by the exercise along with the duplication of the anginal pain. They claimed that the ECG abnormalities in angina patients are due to a reduction of blood flow to the heart. Their published ECG tracings clearly revealed that the ECG findings returned to normal when the chest pain subsided and also when the nitroglycerin was administered in patients with angina pectoris. They performed their exercise tests by having the patients do sit-ups. Prior to these investigators' accomplishments, Einthoven[14] published an ECG tracing demonstrating the S-T segment depression after exercise, although he did not comment on this finding. He probably deserves credit in the field of exercise electrocardiography.

Master[10] published his first paper regarding the exercise test in 1929. He measured only pulse and blood pressure in evaluating the cardiac capacity, and he failed to recognize the value of the electrocardiographic findings to diagnose ischemia. It is interesting to note that Master and Jaffe[11] proposed the importance of taking an electrocardiogram before and after the exercise test to detect coronary insufficiency for the first time in 1941, 12 years after Master's original contribution[10] in 1929.

Wood and Wolferth[15] also described the S-T segment change in patients with coronary heart disease by exercise in 1931, and they pointed out the usefulness of the S-T segment changes in the diagnosis. They proposed that lead V_4 was more useful to detect ischemic changes than the standard limb leads.

In 1932, Goldhammer and Scherf[16] reported the S-T segment depression in 75% of 40 patients with angina, and they proposed the value of exercise to confirm the diagnosis of ischemia due to coronary heart disease.

In 1935, Katz and Landt[17] proposed that lead V_5 was the best lead to bring out the ischemic changes. They tried to standardize their exercise tests by having the patients lift dumbbells while lying on a table.

Missal[18] studied initially normal subjects by having them run up 3 to

6 flights of stairs, but later, in 1938, he used Master's 9-inch steps to exercise his patients. He had his patients exercise to the point of anginal pain and stressed the importance of taking the ECG recording as quickly as possible thereafter.

In 1940, Riseman et al.[19] described the use of continuous monitoring for the first time, and they pointed out that S-T segment depression usually appeared before the onset of anginal pain and usually persisted for a time after the chest pain subsided. They also described the protective effects of O_2 breathing and indicated the presence of mild (up to 1 mm) S-T segment depression in healthy individuals as compared with marked (2–7 mm) S-T segment depression in patients with coronary artery disease. Their conclusion, however, was that the exercise test was of little practical value because of its poor differentiation between the healthy individuals and the coronary patients.

Important recognition of the false positive exercise ECG test due to digitalis effect was described, for the first time, by Liebow and Feil[20] in 1941, and they emphasized that this finding would confuse the diagnosis of true ischemic changes in the exercise ECG.

In 1942, Johnson et al.[21] developed the "Harvard step test" (which was very similar to the original Master's test) while they were working at the Harvard Fatigue Laboratory. The Harvard step test was used widely in athletic circles to assess the physical fitness, and a form of it (the Pack test) was utilized for military purposes. Pulse counts were used during recovery periods for an index of physical fitness.

In 1949, Hecht[22] reported his experience with the anoxemia test, showing 90% sensitivity in the diagnosis of coronary artery disease. He emphasized that the chest pain is an unreliable end point and accompanies ischemia in only 50% of the cases. Hecht also stressed that the S-T segment changes associated with anoxemia may not occur in patients with previous myocardial infarction.

In 1950, Wood et al.[23] described their experience with an effort test at the National Heart Hospital in London. They had patients run up 84 steps adjacent to their laboratory and emphasized that it was necessary to push the patients to the maximal level of their capacity. They concluded that the sensitivity of their test was 88% reliable, compared with a 39% reliability of the Master's test. They further emphasized that the amount of exercise should not be fixed but should be adjusted to the patient's capacity in order to bring out a higher percentage of positive tests in patients with coronary artery disease by giving the maximal exercise.

In 1952, Yu and Soffer[24] proposed the following ECG changes indicating myocardial ischemia by using the Master's test with continuous monitoring:

1. S-T segment depression of 1.0 mm or greater
2. Alteration of the T wave direction from upright to inverted or vice versa
3. Increased amplitude of the T wave of 50% or greater than the resting ECG finding

4. Prolongation of the Q-T/T-Q ratio during exercise to more than two

They again stressed the importance of continuous monitoring. In addition, Yu et al.[25] reported the exercise ECG test using a motor-driven treadmill elevated to a 10–20% grade with continuous monitoring. They proposed a bipolar lead from the right scapula to the lead V_5 position to be used for a treadmill exercise ECG test.

In 1953, Feil and Brofman[26] studied the effect of exercise on the electrocardiogram of bundle branch block. They indicated that transient bundle branch block developing with exercise was first described by Bousfield[12] in 1918. They also reported false positive exercise ECG tests in his patients with Wolff-Parkinson-White syndrome.

Until 1955, the Master's test had been the exercise ECG test of choice, and it is still widely used in many parts of the world where sophisticated and modern exercise laboratory facilities are not available. In 1956, modern exercise ECG tests using a motor-driven treadmill began to receive wide acceptance for research purposes as well as for clinical medicine. Recently, numerous investigators reported data regarding the correlation between the result of the exercise ECG tests and the coronary arteriographic findings (discussed later).

Among many investigators, the following (in alphabetical order) should be recognized as valuable contributors[1–9] in the field of modern exercise electrocardiography: Åstrand, Balke, Blackburn, Bruce, Clausen, Ellestad, Epstein, Fox, Froelicher, Kattus, McHenry, Naughton, Sheffield and many others.

PATHOPHYSIOLOGIC CONSIDERATIONS

The exercise ECG test has two major roles. One role is to determine whether the coronary circulation is capable of increasing oxygen supply to the myocardium in response to increased demands. During physical exercise, myocardial oxygen demands are increased by the increment of systolic pressure, contractile state and the heart rate.[27] Another role of the exercise ECG test is to assess the exercise capacity. The major determining factor of the exercise capacity is considered to be the capability of the heart to increase the cardiac output, providing that there is no evidence of anemia, pulmonary disease, or nervous system or peripheral circulatory disorders.

The heart extracts approximately 70% of the oxygen from each unit of blood perfusing the myocardium at rest,[28] so that oxygen delivery cannot be significantly increased by increased extraction. For practical purposes, myocardial metabolism is entirely aerobic. Thus, coronary blood flow must increase in order to increase the myocardial oxygen supply.[29] It has been shown that in healthy individuals the coronary blood flow increases directly in proportion to increased demands by the myocardium for oxygen.[30] On the other hand, coronary blood flow fails to increase adequately to meet the demands of the myocardium for oxygen in the patients with coronary artery disease leading to myocardial ischemia. Myocardial ischemia may be manifested by anginal pain, S-T, T wave

changes, ventricular dysfunction, various cardiac arrhythmias and any combinations of the above.

It has been well demonstrated that the myocardial oxygen supply may not be reduced significantly at rest to cause myocardial ischemia, even in some patients with severe coronary artery disease. It is not yet settled regarding the degree of coronary artery stenosis to designate a "significant" obstruction. It has been shown in the experimental animal study that reduction of the resting coronary blood flow is produced by an 85% stenosis.[31] During exercise, however, a coronary blood flow is considered significantly reduced when there is at least 50% narrowing.[31, 32] Physical exercise leads to an increment of myocardial oxygen consumption via the increased heart rate, intramyocardial tension and the velocity of myocardial contraction.[33, 34] Acceleration of the heart rate is associated with a reasonably linear increment of myocardial oxygen consumption,[35, 36] and the heart rate during exercise provides a useful parameter of myocardial oxygen requirements. By measuring blood pressure during exercise, the simple product of the heart rate and systolic blood pressure can be calculated, and this result is considered to be a practical index of myocardial oxygen requirements.[34-37]

Detailed descriptions regarding physiologic versus abnormal responses to exercise are found in Chapter 12.

PREPARATIONS AND PRECAUTIONS[1-9]

Needless to say, all exercise ECG tests must be ordered by the physicians. When the order is accepted by the exercise laboratory, the exercise test is scheduled as an elective procedure on either an outpatient or inpatient basis. The patients are instructed to report for their exercise ECG tests either after an overnight fast or 2 hours after a light meal. All patients should be dressed comfortably and the exercise laboratory should be in a comfortable temperature, between 68 and 74°F, with 40–60% humidity. It is preferable to have the patient rest comfortably in the supine position for at least 10 minutes before the actual exercise is performed.

Prior to the exercise ECG test, a complete history should be taken and a thorough physical examination should be performed in order to determine whether the patient is suitable for the test. Indications versus contraindications of the exercise ECG test should be carefully considered (see Chapters 6 and 9). Careful consideration should also be given to whether the patient is taking any drug (e.g., digitalis, propranolol, etc.) which may influence the result of the exercise ECG test (see Chapter 5).

It is mandatory to obtain a 12-lead electrocardiogram in order to determine the presence or absence of any acute cardiac events (e.g., acute myocardial infarction) or any possible contraindications. This author routinely obtains two complete 12-lead ECGs, one before the test and one after the completion of the test for comparison. Chest x-ray is not essential immediately before the test; it is preferable to have a chest x-