

POCKET GUIDE TO
**STRESS
TESTING**

SECOND EDITION

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BRYON A. GENTILE**



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Pocket Guide to Stress Testing

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Second Edition

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To my wife, Leslie, and our children, Elizabeth and Alexander
—Dennis A. Tighe

To my wife, Kaitlin, and our children, Cecelia and Caroline
—Bryon A. Gentile

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Preface

Since the first edition of the *Pocket Guide* was published, the role of stress testing in evaluating patients with suspected cardiovascular disease has been affirmed and new indications have emerged. In addition, new information on the application of stress testing in specific patient populations and the role of myocardial imaging in conjunction with stress testing has continued to evolve. Thus, the impetus for this second edition was to update the reader on the proper application, performance, and interpretation of the various stress testing modalities used in the contemporary stress laboratory. Each chapter has been revised to reflect the most up-to-date information available.

Although abundant information and expansive texts on stress testing are available, we believe that the success of the first edition of the *Pocket Guide* stemmed from its focused content, emphasis on key points, and inclusion of informative illustrations and tables. Therefore, in the second edition we intentionally continued using a format that is bulleted and focused, and makes extensive use of tables and illustrations to present the essential information without over-emphasizing esoteric points. We also include a list of key references in the field at the end of each chapter, so that the reader requiring more detailed information can explore topics of interest in greater depth.

As indications and applications for stress testing have evolved, so has the number of non-physician healthcare professionals involved in the assessment of patients prior to stress testing, during actual performance and monitoring of the test, and issuing of preliminary interpretation of test results. Given the subject matter and practical information included, this edition of the *Pocket Guide* should prove to be a valuable resource to both physicians and non-physicians involved in the care of these patients.

I would like to acknowledge the contributions of my colleagues, who have provided insightful and up-to-date information. My co-author, Bryon A. Gentile, II, deserves special recognition for his contribution of many valuable and

highly informative chapters; without his efforts this edition of the *Pocket Guide* would not have been possible. I wish to acknowledge the staff of Wiley Publishers for their support and cooperation during the process of bringing this project to fruition.

Finally, I wish to pay special recognition posthumously to my mentor, teacher, co-author, and friend, Edward K. Chung, MD. Dr. Chung was an internationally recognized author and leader in the field of electrocardiography and all its applications. He was a generous teacher who demanded excellence and influenced a generation of learners in the heart station at the Thomas Jefferson University Hospital. I was particularly fortunate to have known him and learned from him. It was my distinct privilege to have co-authored the first edition of the *Pocket Guide* with him. I will be forever grateful to him for his wisdom and encouragement.

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Abbreviations

ACC	American College of Cardiology	EF	Ejection fraction
ACLS	Advance cardiac life support	FDA	Food and Drug Administration
ACSM	American College of Sports Medicine	HF	Heart failure
AHA	American Heart Association	HFpEF	Heart failure with preserved ejection fraction
APC	Atrial premature contraction	HFrEF	Heart failure with reduced ejection fraction
ASCVD	Atherosclerotic cardiovascular disease	HLA	Horizontal long-axis
AT	Atrial tachycardia	HR	Heart rate
AV	Atrioventricular	HRR	Heart rate reserve
BLS	Basic life support	Hz	Hertz
BP	Blood pressure	IV	intravenous
bpm	beats per minute	kg	kilogram
BSA	Body surface area	LBbB	Left bundle branch block
CAD	Coronary artery disease	LV	Left ventricle
CHF	Congestive heart failure	LVH	Left ventricular hypertrophy
CPX	Cardiopulmonary exercise test	MAC	Maximal aerobic capacity
DBP	Diastolic blood pressure	METs	Metabolic equivalents
DTS	Duke treadmill score	mg	milligram
ECC	Emergency cardiovascular care	MI	Myocardial infarction
ECG	Electrocardiogram	ml	milliliter

mph	miles per hour	rpm	revolutions per minute
MPI	Myocardial perfusion imaging	RVG	Radionuclide ventriculography
NPO	nothing per oral	SA	Short-axis
MVPS	Mitral valve prolapse syndrome	SBP	Systolic blood pressure
NYHA	New York Heart Association	SPECT	Single photon emission computed tomographic
PACS	Picture archiving and communication system	SV	Stroke volume
PAG	Physical activity guidelines for Americans	VLA	Vertical long-axis
PET	Positron emission tomographic	VO _{2max}	maximal/peak oxygen uptake
Q	Cardiac output	VPC	Ventricular premature contraction
RBBB	Right bundle branch block	VT	Ventricular tachycardia
RER	Respiratory exchange ratio	WPW	Wolff-Parkinson-White
RPE	Rate of perceived exertion		

1 Introduction

Dennis A. Tighe

Introduction

The stress (exercise) ECG test serves as an important and valuable assessment tool that provides diagnostic and prognostic information in the clinical evaluation and management of patients with known or suspected cardiovascular disease, particularly coronary artery disease (CAD).

Various protocols for exercise stress testing have been in existence for several decades. Early protocols for exercise testing, such as Master's two-step test, lacked sufficient sensitivity for clinical use. Currently in the United States, exercise electrocardiography is most commonly performed using a motor-driven treadmill. In Europe, where bicycling is more habitual, exercise stress testing is more commonly performed using a bicycle ergometer.

Several multistage exercise ECG testing protocols have been developed for use with either a motorized treadmill (the Bruce protocol or its modification are the most widely used in the United States) or cycle ergometer (see Chapter 5).

For those unable to perform sufficient physical exertion to adequately complete an exercise ECG test, or when specific clinical conditions exist, pharmacological stress testing with vasodilators or dobutamine is indicated (see Chapter 8). Among patients with resting ECG abnormalities expected to affect repolarization that potentially lead to situations where the ECG response to exercise would be considered non-diagnostic or falsely positive, imaging with echocardiography or myocardial perfusion imaging (MPI) is indicated. Stress echocardiography is also indicated in specific situations in the assessment of valvular heart disease (see Chapter 7). For selected patients with indwelling permanent cardiac pacemakers, the gradual increase of the atrial paced rate can provide an adequate assessment for myocardial ischemia when combined with a myocardial imaging technique.

The exercise ECG test is used primarily to assess the etiology of chest pain and for detection of CAD. In addition, the exercise ECG test can provide important information about functional capacity (prognosis) and the efficacy of medical and surgical therapy for patients with CAD. Furthermore, an exercise ECG test can be quite useful in assessing the ability of an individual to participate in an exercise program or sport (see Chapters 18 and 19), in the evaluation exercise-related symptoms, or for assessment of chronotropic competence or exercise-related arrhythmias.

Myocardial imaging should be performed in combination with the exercise ECG test when false positive or false negative exercise ECG results are anticipated or found and when the exercise ECG test result is equivocal. Due to the infrequent occurrence of ST-segments shifts with pharmacological stress agents, myocardial imaging is required when pharmacological stress testing is performed (see Chapter 11).

Pathophysiologic Considerations

The exercise stress ECG test has two major purposes:

- 1) To determine the capability of the coronary circulation to increase oxygen delivery to the myocardium in response to an increased demand. During physical exertion, myocardial oxygen demand is increased by the increase in systolic blood pressure (SBP), contractile state of the heart, and increase of heart rate (HR).
- 2) To assess the exercise capacity. The major factor determining the exercise capacity is the ability to increase the cardiac output; the product of stroke volume (SV) and HR. In normal individuals, cardiac output (Q) typically increases by a factor of four to sixfold from the resting condition to peak exercise. During moderate to high-intensity exercise, the further increase in Q is primarily attributable to an increase in HR, as SV generally reaches a plateau at 50–60% of maximal oxygen uptake.

As it is known that the heart already extracts approximately 70% of the oxygen from each unit of blood perfusing the myocardium at rest, oxygen delivery to the myocardium cannot be increased significantly by increasing oxygen extraction. For practical purposes, myocardial metabolism is entirely aerobic, thus coronary blood flow must increase in order to augment the myocardial oxygen supply. In healthy individuals, coronary blood flow is documented to increase in proportion to increased myocardial demand for oxygen.

In response to stress in patients with significant CAD, coronary blood flow fails to adequately increase to meet the increased demand of the myocardium for oxygen, leading to myocardial ischemia. Myocardial ischemia may manifest in a variety of ways during a stress test including anginal pain, ST-segment and/or T-wave changes, ventricular dysfunction, various cardiac arrhythmias, or any combination of the preceding.

Physical exercise leads to an increment of myocardial oxygen consumption via the increased HR, intra-myocardial tension, and contractility. With progressive exercise, coronary blood flow can increase as much as four to sixfold above the basal value. Acceleration of the HR is associated with a linear increment of myocardial oxygen consumption; thus the HR response to an exercise bout provides a useful parameter of myocardial oxygen requirements. By measuring the (systolic) BP during exercise, the product of the HR and BP (“double product” or “rate-pressure product”) can be derived, which can serve as a practical index of myocardial oxygen uptake.

Preparations and Precautions

As shall be discussed in further detail in Chapter 2, the exercise ECG test requires certain preparations and due consideration of precautions in order to perform the test appropriately and safely. The nature and purpose of the test should be explained in appropriate detail to the patient. All stress tests must be ordered by a licensed independent practitioner. Upon receipt and acceptance of the order by the stress laboratory, the stress test is scheduled as an elective procedure for outpatients as well as for inpatients.

Patients who are to undergo a stress test should be given the following instructions:

- Report for the test either after an overnight fast or three hours following a light meal.
- Routine medications may be taken with small amounts of water.
- Dress in comfortable clothing and wear comfortable walking shoes or sneakers.

Before a patient is to perform a stress test, the following procedures must be performed:

- A witnessed informed consent document must be obtained by the professional performing/supervising the stress test. This is an important medico-legal requirement (see Chapter 21). Translation services should be provided for non-English-speaking patients.

- A brief history and physical examination should be performed to determine whether the patient is suitable for the proposed test.
- The indication(s) for the test along with any potential contraindication(s) which may exist (see Chapters 3 and 4) should be carefully considered
- Determine whether the patient is taking any medication (e.g. beta-blockers, organic nitrates, calcium channel blockers, digitalis preparation, etc.) that may influence the result(s) of the stress test (see Chapter 15).

The following precautions should be observed prior to initiation of the stress test:

- Maintain the exercise stress laboratory at a comfortable temperature, generally between 68° and 72 °F, with 40–60% humidity.
- Instruct the patient in full regarding the stress test procedure.
- Have the patient rest comfortably in the supine position for a period of 5–10 minutes before the test is performed.
- A standard 12-lead ECG (supine and standing) should be obtained to determine the presence of any acute cardiac events (ECG changes) or any possible contraindications. The modified lead placement with the Mason-Likar (“torso”) system used during stress may alter the inferior lead complexes to either mimic or hide previous Q waves.
- The stress test should be supervised by a licensed, qualified healthcare professional fully familiar with all aspects of the procedure, including use of the equipment, test interpretation, and recognition of potential complications that may arise. If a non-physician (nurse, nurse practitioner, physician assistant, exercise physiologist) is designated to supervise the stress test, a physician skilled in stress testing should be immediately available in the vicinity for consultation and assistance should such a situation arise.

During the test, the procedure should be halted immediately if either of the following occurs:

- The patient requests that the test stop.
- The patient develops significant symptoms (e.g. chest pain, dizziness, dyspnea, etc.), hypotension, cyanosis, bradycardia, or other serious cardiac arrhythmias and/or marked ST-segment changes.

Anyone supervising a stress test must be prepared for emergency situations:

- Although a rare occurrence, all necessary equipment for cardiac resuscitation must be immediately available in the stress laboratory.
- Treating patients immediately for significant symptoms, cardiac arrhythmias, and any other untoward complications.

The staff supervising the stress test must inspect all emergency equipment on a daily basis to ensure that any serious complication can be managed immediately, and all qualified healthcare personnel working in the stress laboratory must be capable of handling any cardiopulmonary emergencies (see Chapter 13).

Methodology

Methods of Stress

- *Exercise (stress) ECG test.* A motor-driven treadmill is the most commonly used device in the United States. Can also be accomplished using a cycle ergometer (more popular in Europe) or an arm ergometer (not commonly utilized).
- *Pharmacological stress testing.* Vasodilators (dipyridamole, adenosine, and regadenoson) or a catecholamine (dobutamine) can be used for those unable to perform an exercise stress test or in specific clinical situations (see Chapters 8 and 11).
- *Artificial pacing.* In selected patients with an indwelling cardiac pacemaker, the device can be used increase HR and assess for inducible myocardial ischemia. In rare instances today, a swallowed pill electrode can be used to pace the heart.

Protocols for the Treadmill Exercise ECG Test

As will be discussed further in Chapter 5, a number of multistage exercise protocols have been devised. In clinical practice, the Bruce protocol is employed most widely. Among certain subsets of patients or for specific clinical situations, an exercise protocol other than the Bruce protocol may be the more appropriate choice.

Planning the Ideal Exercise ECG Stress Test

- The initial workload should be within an individual's anticipated physical working capacity. Workloads should be increased gradually, not abruptly, and should be maintained for a sufficient length of time (generally three minutes) to attain a near physiological study state.
- Continuously monitoring HR, ST-segments, and cardiac rhythm during exercise is essential as is measuring BP during each stage. In addition, it is important to monitor the patient for signs and symptoms (chest pain, dyspnea, dizziness, extreme fatigue, perceived exertion) which may develop during an exercise bout as these may presage development of significant ECG changes or hemodynamic issues. As some abnormal responses occur after exercise, monitoring should continue for six to eight minutes in the post-exercise recovery period, or longer, if the patient is symptomatic or if BP, HR, and/or ST-segments have not returned to near-baseline values.
- An exercise ECG test is most often designed to be "symptom-limited;" most tests should be terminated because of fatigue, significant symptoms, and/or ECG changes rather than attainment of a particular HR goal.
- The exercise ECG test should be terminated immediately if significantly abnormal symptoms, marked ST-segment changes, serious arrhythmias, or significant shifts in blood pressure are found.

Choosing the Exercise ECG Protocol

As stated above, a variety of multistage protocols exist; the Bruce protocol is most widely used.

- With some exercise ECG protocols, workload is increased by changing speed alone while maintaining a fixed grade (incline or elevation).
- In the Bruce protocol, the workload is changed incrementally by increasing both the speed and grade of the treadmill.
- For the progressive increment of workload, three-minute intervals are preferable so that steady-state BP and HR responses can be achieved.
- A submaximal (“low-level”) exercise ECG test protocol is recommended by some cardiologists in the setting of a stable patient following a recent myocardial infarction (MI) or acute coronary syndrome without full revascularization.

Metabolic equivalents (METs), multiples of the basal metabolic rate (1 MET is defined as ≈ 3.5 mlO₂ per kilogram of body weight per minute [ml/kg/min]), are commonly used to express the workload in various stages of the exercise ECG testing protocols.

- In the majority of patients with CAD, a workload of 8 METs is often sufficient for evaluation of angina pectoris.
- Healthy sedentary subjects are seldom able to exercise beyond a workload of 10–11 METs.
- Physically active individuals may be capable of achieving workloads in excess of 16 METs.

When correlating cardiac functional capacity with exercise workload expressed in METs, the following relationships are generally observed:

- Functional class III patients often become symptomatic at a workload of 3–4 METs.
- Functional class II patients often are limited by symptoms at workloads of 5–6 METs.
- Functional class I patients should be capable of achieving workloads in excess of 7–8 METs.

Lead System and Electrode Placement

Electrodes

Obtaining high-quality ECG recordings is the most important aspect for proper interpretation of the ECG stress test. Using appropriate electrodes and proper skin preparation at the site of electrode placement are essential.

- A disposable silver-silver chloride electrode that provides a good skin contact by means of a liquid conductor is the most reliable and optimal electrode.
- Proper skin preparation designed to remove the superficial oils and layer of skin to significantly lower resistance consists of:
 - Cleaning the sites of electrode application with ethyl alcohol.
 - Removing the superficial keratinized layer of epidermis by gentle abrasion.
 - Washing away the removed superficial epidermal layer by a light cleaning such as with acetone.

For the interface between the skin and electrode to be optimal, skin resistance should be reduced to 5000Ω or less. After electrode placement, the technician should tap lightly on the electrode to assess adequacy of skin preparation (no noise on the ECG should be created with the tap).

In addition, efforts should be taken to minimize motion at the electrode-cable interface. This may be achieved by creating stress loops with precut tape strips or securing the cables centrally with an elastic belt worn around the waist. Disposable mesh vests placed on the upper torso can help secure the electrodes.

For women, particularly those with large breasts, a breast support garment should be worn during the exercise ECG test in order to minimize motion artifacts which can obscure diagnostic ECG changes and hide potentially dangerous arrhythmias during exercise.

Lead Systems

While historically single-channel lead systems such as monitoring lead V5 or bipolar lead CM5 were demonstrated to have high sensitivity for detecting myocardial ischemia compared to 12-lead ECG recordings, current systems utilize multiple ECG leads.

- Use of multiple leads has been shown to increase test sensitivity.
- In recording systems using multiple leads, the lateral precordial leads (leads V4 through V6) are capable of detecting 90% of all instances of ST-segment depression.
- In our laboratory, we monitor leads II, V1, and V5 continuously during stress and recovery. At the end of each stage (and periodically as required), a 12-lead ECG can be displayed and printed.
- The Mason-Likar (“torso”) modification of lead placement is used during exercise to minimize muscle and motion artifact.

Observation

Most laboratories continue to use visual observation and interpretation (see Chapter 14) of the exercise ECG. Most modern ECG systems used for exercise testing collect data that would allow for computerized assessment of the exercise ECG test, particularly ST-segment abnormalities, which may enhance the predictive accuracy of the test (see Chapter 20).

Endpoints to Terminate Exercise ECG Stress Tests

A detailed description of the endpoints for the exercise ECG test is provided in Chapter 5. In general, a symptom-limited test (rather than a HR-limited test) to near-maximum level gives the most diagnostic information as well as providing assessment of exercise capacity/prognosis.

The qualified healthcare professional supervising the test must be able to make a correct, instant decision for each patient as to whether the exercise bout should continue or be terminated.

- Encourage the patient to continue when it is apparent that a lack of motivation is present and all parameters show expected (normal) findings.
- It is important to speak with the patient intermittently and to observe facial expression during exercise. These actions may help to assess whether the patient may have any unusual distress. Patients may try to overcome serious symptoms and not report them to the test supervisor.

When to Terminate the Exercise Prematurely

Patient-determined and provider-determined indications are recognized.
Absolute indications include:

- The patient requests that the test stop.
- Significant symptoms, such as chest pain, dizziness, marked dyspnea, or severe fatigue, are produced.
- Signs such as ataxia, pallor, or cyanosis are observed.
- The patient experiences symptoms of an intensity that would prompt stopping daily activities. Do not insist that the patient continue on to reach a predicted HR.
- The patient develops ST-segment elevation (>1.0 mm) in leads without pre-existing Q waves because of prior MI (exceptions: leads aVR, aVL, and V1).
- Occurrence of severe cardiac arrhythmias, such as sustained ventricular tachycardia (VT) or other arrhythmia, including second- or third-degree atrioventricular block, preventing normal maintenance of cardiac output during exercise.
- A decline in systolic BP >10 mmHg occurs despite an increase in workload, when accompanied by any other evidence of myocardial ischemia.
- Development of technical difficulties in the monitoring/interpreting of the ECG or BP.

Relative indications include:

- Marked ST-segment displacement (horizontal or downsloping of >2 mm, measured 60–80 ms after the J point) in a patient with suspected ischemia.
- A decline in systolic BP >10 mmHg (persistently below baseline) despite an increase in workload, in the absence of other evidence of myocardial ischemia.
- Presence of arrhythmias other than sustained VT, including multifocal ventricular ectopy, ventricular triplets, supraventricular tachycardia, and bradyarrhythmias with the potential to become more complex or cause hemodynamic instability.
- Occurrence of an exaggerated hypertensive response, defined as SBP >250 mmHg or diastolic BP >115 mmHg.
- Development of bundle branch block that cannot immediately be distinguished from VT.

Indications Versus Contraindications (see Chapters 3 and 4)

Major Indications of the Exercise ECG Test

- Confirmation or exclusion of CAD; assessment of the etiology of chest pain or equivalent symptom.
- Assessment of functional capacity (exercise tolerance).
- Evaluation of the efficacy of medical and/or surgical treatment for CAD.

Minor Indications of the Exercise ECG Test

- Assessment of the nature of certain (exercise-induced) cardiac arrhythmias and chronotropic incompetence.
- Evaluation of exercise-related symptoms.