Exercise Standards for Testing and Training: A Scientific Statement From the American Heart Association

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on behalf of the American Heart Association Exercise, Cardiac Rehabilitation, and Prevention Committee of the Council on Clinical Cardiology, Council on Nutrition, Physical Activity and Metabolism, Council on Cardiovascular and Stroke Nursing, and Council on Epidemiology and Prevention

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The 2001 version of the exercise standards statement[1] has served effectively to reflect the basic fundamentals of ECG–monitored exercise testing and training of both healthy subjects and patients with cardiovascular disease (CVD) and other disease states. These exercise standards are intended for use by physicians, nurses, exercise physiologists and specialists, technologists, and other healthcare professionals involved in exercise testing and training of these populations. Because of an abundance of new research in recent years, a revision of these exercise standards is appropriate. The revision deals with basic fundamentals of testing and training, with no attempt to duplicate or replace current clinical practice guidelines issued by the American Heart Association (AHA), the American College of Cardiology Foundation (ACCF), and other professional societies.

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Evaluation of Chest Pain in the Emergency Department

Detailed recommendations for exercise testing among patients who present to the emergency department (ED) or chest pain centers are presented in the AHA science advisory on "Safety and Utility of Exercise Testing in Emergency Room Chest Pain Centers,"[321] the "ACC/AHA 2002 Guideline Update for Exercise Testing,"[58] and the AHA scientific statement on "Testing of Low-Risk Patients Presenting to the Emergency Department With Chest Pain."[322] Patients who present to the ED are a heterogeneous population with a large range of pretest probabilities of CAD. In accord with Bayesian principles, the greatest incremental diagnostic value occurs in intermediate-risk clinical patient subsets. Exercise treadmill testing should be considered in patients who present to the ED with symptoms such as chest discomfort when they are classified as "low risk," which includes the following: Two sets of cardiac enzymes at 4-hour intervals are normal; ECG at the time of presentation and before the exercise test shows no significant changes; the resting ECG has no abnormalities that preclude accurate assessment of the exercise ECG; and the patient is asymptomatic or has minimal atypical chest pain from admission to the time results are available from the second enzyme set.[323]

Early exercise testing has been applied in patients with chest pain who are identified as low risk by clinical assessment, which has been implemented by using 2 approaches. In most studies, it is performed soon after presentation after an acute coronary syndrome has been excluded. Acute coronary syndromes are ruled out by an accelerated diagnostic protocol, which is usually performed within a 6- to 12-hour interval with serial cardiac serum markers and ECGs. In the second, less common, strategy, selected low-risk patients undergo "immediate" exercise testing to stratify the group into those who can be discharged directly from the ED and those who require admission. Both methods have thus far been shown to be safe, informative, and cost-effective, although experience with the latter is considerably more limited than with the former.

The feasibility of "early" exercise testing after excluding an acute coronary syndrome has been demonstrated by a number of studies involving 100 to >400 patients presenting with chest pain and negative results on an accelerated diagnostic protocol.[324–329] Patients with negative exercise tests were discharged, and those with positive results were admitted. No adverse effects of exercise testing were reported. Direct discharge of patients after a negative exercise test reduced hospital admissions for the initial presentation by ≈50%.[324,326] A negative exercise test was associated with no cardiac events at 30 days[325] and at 5-month[328] follow-up. Compared with patients with a positive test, those with negative tests had equivalent[324,326] or fewer readmissions[327] at 1 to 6 months. Substantial cost savings also have been demonstrated with an accelerated management protocol that included exercise testing.[325,326]

In further studies from one center, exercise testing was used in low-risk ED patients presenting with chest pain who had normal, near-normal, or unchanged ECGs.[323,330–332] This procedure has been applied in >1000 patients[332] with no reported adverse effects of exercise testing. All of those in the group with negative exercise tests were discharged directly from the ED, and follow-up at 30 days revealed a cardiac event in <1%. However, this approach has been associated with a small risk (<1.0%) of inadvertent exercise testing of patients with evolving, non–ST-elevation MI, but it has been associated with no complications.[332] When performed after ruling out MI, early exercise testing in the ED or in chest pain units seems to be safe, accurate, and cost-effective.

SPECT imaging and dobutamine echocardiography have also been used in the ED for the noninvasive identification of myocardial ischemia and its effects on regional myocardial function.[333,334] Direct noninvasive visualization of coronary artery stenoses with 64-slice coronary computed tomography angiography performed well for predicting absence of acute coronary syndrome in an observational cohort study and could become an important triage alternative to traditional exercise testing in ED patients with acute chest pain syndromes.[335,336]

Known or Suspected Arrhythmias

Comprehensive ACCF/AHA/ European Society of Cardiology guidelines for management of patients with ventricular arrhythmias were published in 2006.[337] Class I recommendations for exercise testing include adult patients with ventricular arrhythmias who have an intermediate or greater probability of having coronary disease and patients (regardless of age) with known or suspected exercise-induced ventricular arrhythmias, for provocation, to make a diagnosis, and to evaluate the response to tachycardia. Exercise testing is considered useful, Class IIa, for evaluating the response to medical or ablation treatment in patients with known exercise-induced ventricular arrhythmias. Class IIb recommendations include patients with arrhythmias but a low probability of CAD and for the evaluation of isolated ventricular premature beats in greater than middle-aged patients without other evidence of CAD. In a scientific statement on risk for sudden cardiac death, assessment of functional capacity by peak oxygen consumption and by the 6-minute walk test was considered more accurate than clinical variables such as functional classification for the prediction of death and sudden death in chronic heart failure.[338]

The application of other available guidelines to exercise testing in patients with known or suspected arrhythmias but nonatherosclerotic heart diseases was recently reviewed by Morise.[339] Specifically considered were hypertrophic cardiomyopathy (HCM), valvular heart disease, atrial fibrillation, documented VT, pacemakers, and T-wave alternans. Class I indications for exercise testing include the assessment of HR-adaptive pacemakers and individuals with congenital complete heart block who are contemplating increased physical activity or competitive sports. Class IIa indications include arrhythmia provocation in patients with known or suspected exercise-induced arrhythmias, including evaluation of medical, surgical, or catheter ablation therapy in such individuals; evaluation of ventricular rate response and suspected myocardial ischemia in patients with atrial fibrillation; and in combination with T-wave alternans testing in patients with or at risk for life-threatening ventricular arrhythmias.

In some individuals, arrhythmias can occur primarily in relation to vigorous exercise. The prototype for such arrhythmias is catecholaminergic VT, a disorder first described in 1975, which occurs in genetically predisposed people without structural heart disease. In these individuals, the arrhythmia is often not inducible by programmed electrical stimulation but

is nearly always inducible by exercise testing.[340] β-Adrenergic blockade can be lifesaving in these patients. In patients with long-QT interval syndrome, exercise testing may elicit QT prolongation, which can be useful in risk stratification.[341]

T-wave alternans represents macroscopic or measurable microscopic alternation in electrocardiographic T-wave amplitudes or morphology that can be related to potential electrical instability. T-wave alternans testing performed in conjunction with exercise testing can be useful in identifying patients at risk for developing life-threatening ventricular arrhythmias. Numerous studies and a meta-analysis have shown low positive predictive value but high negative predictive value for such testing in predicting these arrhythmias.[342–344] Thus, a negative test is reassuring, whereas a positive test suggests that further risk stratification is needed.

In patients with rate-adaptive pacemakers, exercise testing can help to optimize the HR response and increase exercise capacity.[58] Such testing can be especially useful in patients whose exercise intolerance is not improved by pacing or empirical pacemaker adjustments.

Patients with atrial fibrillation not uncommonly demonstrate exaggerated ventricular rate responses to low-level exercise even when resting HR appears well controlled. Exercise testing can identify such individuals and can be used to titrate ventricular rate response through medication adjustment to optimize exercise capacity. Exercise testing also can detect QRS widening after initiating Class 1C antiarrhythmic drugs in patients with atrial fibrillation.

Heart Failure

CPX is now a well-established clinical assessment procedure in patients with heart failure.[19] Although the general approach to exercise testing in the heart failure population is similar to other groups, selection of the optimal testing protocol for the individual patient warrants special consideration. Given that most patients with heart failure have a significantly diminished functional capacity, the exercise test protocol should typically be conservative in nature.[19] Both peak $\dot{V}o_2$ and variables reflecting ventilatory efficiency, such as the $\dot{V}e/\dot{V}co_2$ slope, have been shown consistently to reflect disease severity, to be strong prognostic markers, and to serve as useful gauges of therapeutic efficacy.[345,346] Although both variables provide independent predictive value, a combined peak $\dot{V}o_2$ <10 mL kg^{-1} min^{-1} and a $\dot{V}e/\dot{V}co_2$ slope >40 portend a particularly poor prognosis and reflect advanced heart failure severity.[19] Other ventilatory expired gas and traditional exercise test variables have also demonstrated additive prognostic value through multivariate modeling,[347] although additional research is needed before solidifying recommendations for clinical practice.

Pulmonary Hypertension

The role of CPX in assessing pulmonary hemodynamics is a rapidly emerging field demonstrating a great deal of clinical promise.[19,348,349] Patients diagnosed with pulmonary arterial hypertension typically present with a level of diminished aerobic capacity, correlating with disease severity. Perhaps more importantly, measures of ventilatory efficiency, specifically the $\dot{V}e/\dot{V}co_2$ slope or ratio and the partial pressure of end-tidal CO_2 during exercise, reflect the degree of elevation in pulmonary arterial pressure and therefore disease severity. These latter variables are particularly important in this patient population, given their association with pulmonary ventilation–perfusion mismatching, a primary consequence of pulmonary arterial hypertension. Initial evidence indicates that these CPX variables are both prognostic and gauge therapeutic efficacy in patients with pulmonary arterial hypertension.[348] Also, in patient populations in whom pulmonary hypertension could become a secondary consequence, such as in heart failure, HCM, chronic obstructive lung disease, and interstitial lung disease, ventilatory inefficiency (abnormally elevated $\dot{V}e/\dot{V}co_2$ and abnormally diminished partial pressure of end-tidal CO_2 during exercise) appears to accurately identify an elevated pulmonary artery pressure.[350]

Adult Congenital Heart Disease

Adults with congenital heart disease usually have cardiovascular issues that are distinct from those encountered among other adult cardiology patients. The role of exercise testing in the assessment and management of this unique group therefore differs substantially from that associated with typical adult cardiology patients. In general, the primary goal of exercise testing in adults with congenital heart disease is not the detection or evaluation of CAD. Rather, purposes of the test include the following:

- Assessment of the patient's exercise capacity
- Identification of factors that limit exercise performance
- Derivation of information on risk of cardiovascular and all-cause death
- Objective determination, based on serial testing, of whether there has been a change in clinical status or exercise capacity
- Assessment of the impact of therapeutic interventions on exercise function

These assessments are productively informed by data acquired at peak exercise during CPX testing ($\dot{V}o_2$max, peak HR, peak work rate, and the oxygen pulse at peak exercise). The validity of these data depends on adequate effort expenditure by the patient. Therefore, for most adult congenital heart disease patients, it is inappropriate to arbitrarily terminate an exercise test when the patient achieves 85% of predicted peak HR or any other preconceived HR threshold. In addition, many adult patients with congenital heart disease have abnormal sinus node function as a result of their underlying defects, prior surgeries, or current medications. Using a patient's peak HR as an indicator of effort is therefore unreliable.[268] It is preferable to rely on the respiratory exchange ratio; if the respiratory exchange ratio is <1.09, it is unlikely that a patient has approached his or her cardiovascular limit.[351] $\dot{V}o_2$max has been found to be an independent predictor of death or hospitalization in a variety of congenital heart defects, including tetralogy of Fallot,[352] repair of transposition of the great arteries,[353] and Fontan physiology.[354] Similarly, in a recent study, Fontan patients with a peak HR <123 bpm were found to have a 10.6-fold greater risk of death during a follow-up period of 4.0±2.0 years.[354] In that study, however, almost all of the patients with a low peak HR had undergone treatments for serious rhythm disturbances. Thus, it is unclear whether the low peak HR was an independent risk factor for death or merely a marker for a history of serious arrhythmias.