



OREGON
HEALTH & SCIENCE
UNIVERSITY

**Division of
Pulmonary-Critical
Care Medicine
Physiology Rotation**

Overview of Goals and Objectives of Rotation: Exercise Physiology Rotation

Medical Director: Alan Barker

Preceptors: Alan Barker, Daniel O'Hearn

ACGME Training Guidelines:

Fellows must have formal instruction, clinical experience, and must demonstrate competence in the evaluation and management of patients in pulmonary rehabilitation.

The program must be structured to permit all fellows to develop the requisite procedural and technical skills, including the ability to interpret data derived from various bedside devices commonly employed to monitor patients. Fellows must have formal instruction, clinical experience, and must demonstrate competence in the following: pulmonary function tests to assess respiratory mechanics and gas exchange, including spirometry, flow volume studies, lung volumes, diffusing capacity, arterial blood gas analysis, and exercise studies.

Fellows must have formal instruction and clinical experience in performing the following: inhalation challenge studies monitoring and supervising special services,

The training program must provide formal instruction for the fellows to acquire knowledge of the following content areas including:

a) respiratory care units;

b) pulmonary function laboratories, including quality control, quality assurance, and proficiency standards; and

c) respiratory care techniques and services. pulmonary physiology and pathophysiology in systemic diseases; skills required to organize, administer and direct a respiratory therapy section and to work effectively as a member of a multidisciplinary team;

Objectives for a Pulmonary and Critical Care Fellow on a Pulmonary Function Rotation

1. Become familiar with various types of spirometers; those acceptable for screening, office, bedside, and hospital.
2. Review ATS Guidelines for spirometry performance, practice and interpretation.
3. Understand role and limitations of bronchodilator testing
4. Calculate FVC, FEV₁, FEF 25-75 for at least 2-4 spirograms. Compare with computerized values.
5. Become familiar with QA programs for spirometry to include internal and external FVC checks, biologic controls, technician checks
6. Review current interpretative spirometry programs. Render suggestions for modification OHSU Macros and ways to be more iterative.
7. Review principles of lung volume measurements.
8. Learn advantages and disadvantages of gas dilution, washout, and thoracic gas volume measurements
9. Understand use of lung volumes in conjunction with spirometry (low FVC)
10. Become familiar with principles of DLCO (gas transfer). Understand assumptions made in measurement
11. Understand best ways to standardize DLCO measurements.
12. Understand role of 6 minute walk as tool of functional assessment.
13. Learn role of walk test as oxygen needs assessment. Become familiar with the oxygen prescription and Medicare guidelines for its application
14. Become familiar with principles of and uses of oxygen delivery systems (concentrator, pressure, liquid; continuous, reservoir, demand flow)
15. Understand use and role of respiratory pressures in suspected neuromuscular respiratory conditions

16. Become familiar with use integrative cardiopulmonary testing to include indications, measurements performed, interpretation, safety precautions. Understand role as adjunct to other cardiopulmonary tests. Become familiar with AMA guidelines in describing impairment.
17. Understand role of bronchoprovocation testing to include methacholine and exercise. Become familiar with safety precautions for patients and personnel.
18. Understand role of pulmonary function in clinical research to include which tests are helpful or useful as endpoint determinations.
19. Appreciate scheduling needs and timing of various pulmonary function tests and how to integrate with various functions of the laboratory.

Potential Role of Fellow in Pulmonary Function Laboratory

1. Attend Hospital (and/or clinic) PF laboratory 2-3 ½ days/week
2. Learn and perform spirometry with assistance RC technician
3. Observe all other testing noted in Objectives
4. Assist Fellows and trainees with interpretation of PF during their rotations
5. Coordinate Fellow attendance at cardiopulmonary testing
6. Learn how to interpret cardiopulmonary testing
7. Perform QA on several sets of spirograms
8. Review literature for each testing PF modality and update with current pertinent articles/guidelines. Develop (electronic) library
9. Help develop a syllabus incorporating one or more of Objectives. Present to RC technical group and PCC division during a conference.
10. Help promote pulmonary function among OHSU staff, trainees, and the community.

Instructional Methods:

Methods of Assessment:

References:

Applied Physiology:

Pressure-Flow Relationship in the Lungs, Roland Ingram, TJ Pedley, Handbook of Physiology, Section 3, Volume III, Chapter 18, 277-294

Pulmonary Circulation, Alfred Fishman, Handbook of Physiology, Section 3, Volume I, Chapter 3, 93-166

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Fundamental Measurements:

Static behavior of the Respiratory System, Emilio Agostoni, Robert Hyatt, *Handbook of Physiology*, Section 3, Volume III, Chapter 9, 113-127

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Physiology in Disease States:

The Chest Wall and Respiratory Muscles in Chronic Obstructive Pulmonary Disease, Andre De Troyer, Neil Pride, *The Thorax*, Part C, Marcel-Dekker, Chapter 68, 1975-2006

Respiratory Muscle Fatigue: Rationale for Diagnostic Tests, E Devito, Alejandro Grassino, *The Thorax*, Part C, Marcel-Dekker, Chapter 64, 1857-1880

Dynamics of Breathing in Ventilatory Failure, Rolf Hubmayr, *The Thorax*, Part B, Marcel-Dekker, Chapter 59, 1685-1708

Measurement of the Work of Breathing in the Critically Ill, Apostolos Armaganidis, Charis Roussos, *The Thorax*, Part B, Marcel-Dekker, Chapter 42, 1231-1374

Pulmonary Rehabilitation;

American Thoracic Society: Pulmonary Rehabilitation-1999, *AJRCCM* 1999;159:1666-1682

State of the Art:Pulmonary Rehabilitation in Chronic Obstructive Pulmonary Disease, Troosters T, et al, *AJRCCM* 2005;172:19-38

Standards for the Diagnosis and Management of Patients with COPD: A Joint Statement of the ATS &ERS, 2004: 1-222

Special Populations:

Respiratory Care of the Patient with Duchenne Muscular Dystrophy:ATS Consensus Statement *AJRCCM* 2004;170: 456-465

Standards of Spirometry:

General considerations for lung function testing, Miller, MR, et al, *ERJ* 2005; 26: 153-161

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Interpretative strategies for lung function tests, Pelligrino R, et al, *ERJ* 2005; 26: 948-968

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CD PDFs:Table of Contents

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Update on Clinical Exercise Testing: Part 1

By Darcy D. Marciniuk, MD, FCCP; and Idelle M. Weisman, MD, FCCP

Objectives

1. To review recent scientific advances in methods and results of exercise testing that are of importance to the practicing clinician.
2. To recognize the utility and limitations of assorted methods of exercise testing.
3. To understand appropriate indications for exercise testing in the assessment and management of patients.
4. To appreciate that exercise testing results can have greater clinical meaning when interpreted within the context of relevant patient information.
5. To recognize that additional study is required to further characterize both the current and future roles of exercise testing in clinical medicine.

Key words: exercise; heart; interpretation; lung; methodology; 6-min walk test; testing

Abbreviations

CET = clinical exercise testing; PPH = primary pulmonary hypertension

Clinical exercise testing (CET) is playing an increasingly important role in clinical medicine by allowing the practicing clinician to objectively evaluate important physiologic functions. The results from exercise testing more accurately parallel functional capacity and quality of life than resting measurements, and have been shown to accurately predict outcomes and also mortality in a variety of clinical circumstances.

In this brief two-part update, we will highlight recent advances in our appreciation of the role of exercise testing in clinical medicine, review our increased understanding about differing methods to assess exercise performance and responses, and outline appropriate indications for the conduct of CET in clinical practice.

Part 1: Advances in the Utility of Exercise Testing in Clinical Medicine

There have been many recent studies examining the value of exercise testing in predicting outcomes and mortality, in correlating with disease severity, in evaluating exercise intolerance and response to therapy, in optimizing exercise prescription, and in the early detection of physiologic impairment(s) associated with specific diseases.

COPD

The results from exercise testing (6-min walking distance) have been shown to predict mortality in COPD. When combined with the body mass index, the degree of airflow obstruction, and sense of dyspnea to form a multidimensional scale, a composite score was better than the FEV₁ taken in isolation at predicting the risk of death from any cause, and from respiratory causes among patients with COPD.¹

In another study of 150 patients with moderate COPD (FEV₁ 47% predicted), the peak oxygen uptake and the St. George's Respiratory Questionnaire total score were both predictive of mortality, independent of FEV₁ and age.² Stepwise Cox proportional hazards analysis revealed that the peak oxygen uptake derived from exercise testing was the most significant predictor of mortality in this population of COPD patients with a mean FEV₁ of 1.01 L (38% predicted) (Fig 1).²

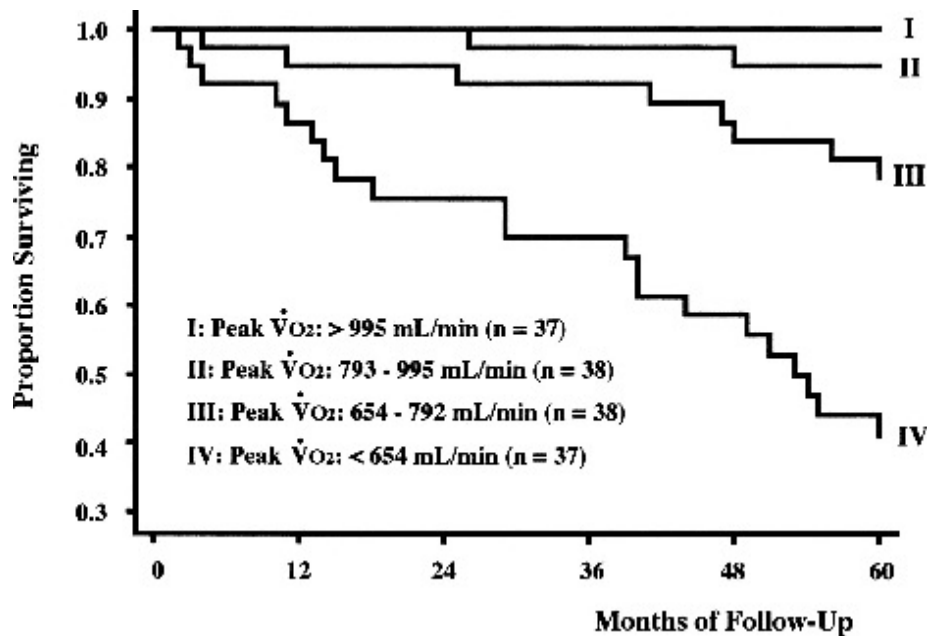


Figure 1. Kaplan-Meier survival curves using quartiles of the peak oxygen uptake distribution in patients with COPD (n=150). Reprinted with permission from Oga et al.²

The multifactorial etiology of exercise intolerance and the significant potential contribution of limb muscle fatigue in patients with COPD were highlighted in a study³ of 18 patients with severe COPD (mean FEV₁, 1.03 L). Subjects performed exhaustive constant-work cycling while contractile fatigue of the quadriceps muscle (potentiated twitch force of the quadriceps) was assessed before and after the crossover administration of either 500 µg of ipratropium bromide or placebo. Although peak minute ventilation/maximal voluntary ventilation (used as a surrogate for ventilatory limitation) averaged 97%, and there was a trend for improvement of endurance time (p=0.06) in the whole group, endurance time in some patients did not improve after the bronchodilator administration; in these patients, quadriceps fatigue was the major apparent reason for exercise limitation. Fatiguers and nonfatiguers could not readily be distinguished, suggesting that additional work is necessary to better characterize these patients. Interestingly, in another study comparing shuttle walking and cycle ergometry, quadriceps fatigability occurred after incremental and constant-work (endurance) cycle ergometry, but not after incremental and endurance shuttle walking.⁴ Differences in muscle mass and relative amounts of fatigue per recruited muscle used in cycling vs walking may provide possible explanations; this issue requires further investigation.

CET was also found to be useful in optimizing exercise prescription for pulmonary rehabilitation by quantitatively demonstrating the significant additional benefits of administering supplemental oxygen during exercise training in nonhypoxemic patients with severe COPD (mean FEV₁, 1.01 L).⁵

Interstitial Lung Disease

The role of CET in the physiologic assessment of interstitial lung disease has recently been reviewed.^{6,7} Our understanding of the benefit(s) and utility of exercise testing in the early diagnosis, in assessing disease severity, and in predicting outcome in these diseases has been advanced by recent literature. Specifically, the role of CET in the early detection of physiologic impairment and also in assessing disease severity (when compared with resting measurements

or investigations) has been validated in sarcoidosis,⁸ lymphangiomyomatosis,⁹ and asbestosis.¹⁰ Recent reports have also highlighted that the results from CET are valuable in predicting outcomes and survival in idiopathic pulmonary fibrosis, usual interstitial pneumonia, and nonspecific interstitial pneumonia.^{11,12}

Primary Pulmonary Hypertension

In patients with primary pulmonary hypertension (PPH), the New York Heart Association class correlates well with reduced peak oxygen uptake and ventilatory efficiency during exercise, but less well with resting pulmonary hemodynamics.¹³ Long-term survival after treatment with vasodilator therapy in PPH has also been shown to correlate with initial exercise impairment (6-min walk distance ≤ 250 m).¹⁴ In addition, the strongest predictors of survival in patients with PPH have been reported to be a low peak oxygen uptake (≤ 10.4 mL/kg/min) and low systolic blood pressure at peak exercise (≤ 120 mm Hg).¹⁵ Interestingly, hemodynamic parameters, although found to also be accurate predictors, provided no independent prognostic information. After adjusting for pulmonary vascular resistance, the only other independent variable predictive of mortality in patients with untreated PPH is exercise desaturation.

The 6-min walk test reflects exercise capacity (peak oxygen uptake) determined by maximal CET in patients with PPH ($r=0.70$; $p<0.001$), and also has a strong, independent association with mortality (walking <332 m during the 6-min walk test).¹⁶

Congestive Heart Failure

In 644 patients with congestive heart failure, the peak oxygen uptake derived from CET outperformed clinical variables and right-heart catheterization data in predicting outcome in severe disease.¹⁷ Furthermore, in men referred for cardiac treadmill exercise testing for various clinical reasons, peak absolute exercise capacity was a more powerful predictor of mortality than other more established risk factors for cardiovascular disease.¹⁸

In 303 patients with stable chronic heart failure, a lower peak oxygen uptake, and an elevated ratio of minute ventilation to carbon dioxide output slope were both highly significant prognostic indicators¹⁹ (Fig 2). In another population of patients with heart failure, the use of β -blockers did not change the strong predictive power of the exercise peak oxygen uptake; a peak oxygen uptake >14 mL/kg/min was associated with a 1-year event rate of approximately half of that associated with a peak oxygen uptake ≤ 14 mL/kg/min²⁰ (Fig 3).

Common methods to assess exercise responses and performance, as well as clinical indications for exercise testing, are reviewed in Part 2 of this update.

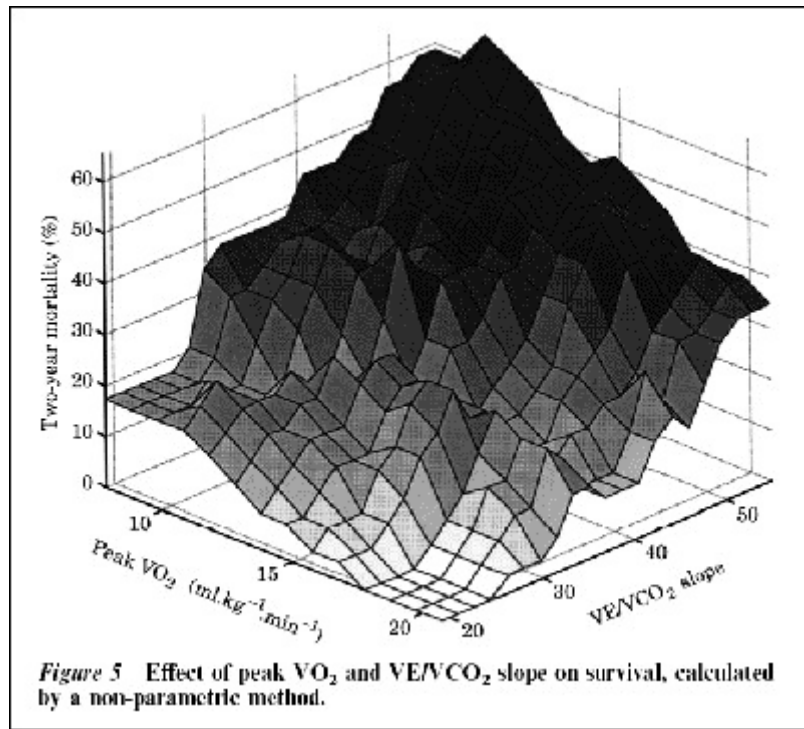


Figure 2. CET for prognosis in congestive heart failure: continuous and independent prognostic value from minute ventilation/carbon dioxide output slope and peak oxygen uptake. Reprinted with permission from Francis et al.¹⁹

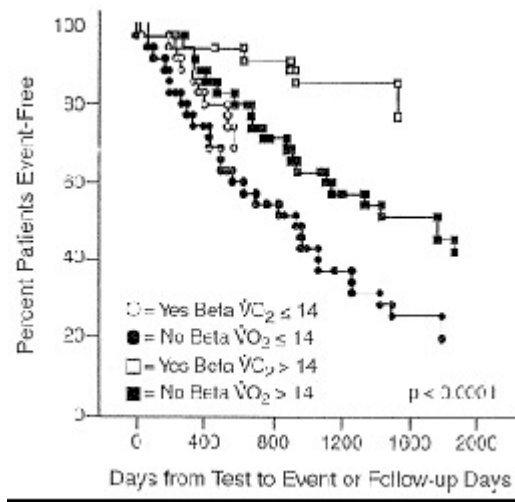


Figure 3. Event-free survival of CHF patient subgroups, divided by β -blocker status and by peak exercise oxygen uptake peak level. Reprinted with permission from Peterson et al.²⁰

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Update on Clinical Exercise Testing: Part 2

Objectives

1. To review recent scientific advances in methods and results of exercise testing that are of importance to the practicing clinician.
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3. To understand appropriate indications for exercise testing in the assessment and management of patients.
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Key words: exercise; heart; interpretation; lung; methodology; 6-min walk test; testing

Abbreviations

6MWT = 6-min walk test; CET = clinical exercise testing; EIB = exercise-induced bronchoconstriction; SWT = shuttle walk test

Clinical exercise testing (CET) is playing an increasingly important role in clinical medicine by allowing the practicing clinician to objectively evaluate important physiologic functions. The results from exercise testing more accurately parallel functional capacity and quality of life than resting measurements, and have been shown to accurately predict outcomes and also mortality in a variety of clinical circumstances.

In this brief two-part update, we will highlight recent advances in our appreciation of the role of exercise testing in clinical medicine, review our increased understanding about differing methods to assess exercise performance and responses, and outline appropriate indications for the conduct of CET in clinical practice.

Part 2: Common Methods to Assess Exercise Responses and Performance

Assessment of exercise responses and performance can be undertaken by a variety of methods with various degrees of complexity. Simple tests are readily performed, but provide limited physiologic understanding. Alternatively, more comprehensive testing may provide more detailed information and understanding, but is both costly and technically demanding. The choice of which test to use therefore depends on the clinical setting and the specific question(s) being addressed and has recently been reviewed.^{1,2} Common types of exercise testing include the 6-min walk test (6MWT), shuttle walk test (SWT), exercise-induced bronchoconstriction (EIB) testing, cardiac stress test, and CET.

The 6-Min Walk Test

The 6MWT is a safe, simple, and practical test of submaximal functional capacity that measures the maximal distance walked by a subject in 6 min.³ Standardization of the testing procedure, including the length and layout of the hallway and encouragement provided, improves the reproducibility of the test results.³ An advantage of the 6MWT is that it purportedly reflects daily activities yet also provides an acceptable index of functional disability, and has been found to correlate with the peak oxygen uptake measured during more comprehensive testing.⁴ However, because it is self-paced by the subject, work rate cannot be controlled; also, a training effect may be evident, particularly in inactive patients. In addition, it provides very limited information regarding physiologic contributors to activity-related symptoms, or about mechanisms of exercise limitation. Its current clinical usefulness lies primarily in evaluation for lung transplantation and

lung volume reduction surgery,^{5,6} pulmonary rehabilitation,³ and in predicting mortality in cardiac patients and patients with pulmonary vascular disease.^{4,7,8}

Shuttle Walk Test

The SWT measures the distance walked by a patient on a 10-m course while being paced by audio signals from a cassette tape.⁹ The intensity of exercise reached is comparable to maximal tests performed on a treadmill, because walking speed is progressively increased until the patient achieves exhaustion. Modification of the maximal SWT for the determination of endurance performance—similar to maximal and constant (submaximal) cycle ergometry—may also be done. Inherent in its design, the SWT correlates better with peak oxygen uptake max than the 6MWT.¹⁰ However, the SWT is much less commonly used than the 6MWT, and additional study examining safety issues, minimal clinically important differences, and reference values are needed.

EIB Testing

EIB is a common disorder in which physical activity triggers acute airway narrowing in a person with heightened airway responsiveness.¹¹ In susceptible patients, EIB typically occurs 5 to 10 min after exercise and generally resolves spontaneously in 20 to 30 min.¹² The diagnosis of EIB is not usually difficult to establish, and is frequently made by the history. However, in some clinical situations, particularly when an inhalational challenge is unavailable or is not diagnostic, formal testing for EIB should be undertaken.¹¹ Common protocols include exercise on a treadmill or cycle ergometer at a workload equivalent to about 60 to 80% of predicted maximum, or at an intensity that will elicit a heart rate of 80% of the predicted maximum for 6 to 8 minutes.^{11,12} The goal is to achieve appropriately high levels of ventilation (40 to 60% of the predicted maximal ventilation) at least equal to those attained during the activity that produces the symptoms of EIB.¹³ In this setting, a 15% fall in the FEV₁ in the time period following exercise would be considered diagnostic of EIB, while a 10 to 15% fall in FEV₁ would be suggestive of EIB.¹¹⁻¹³

Cardiac Stress Test

The cardiac stress test is a common type of exercise testing the primary purpose of which is in the diagnosis and management of myocardial ischemia.¹⁴ The Bruce protocol is the most widely used protocol, and the single most reliable indicator of ischemia during the test is ST-segment depression.¹⁴ While the test is typically undertaken on a treadmill with monitoring of the ECG and blood pressure, the diagnostic utility may be enhanced by the concurrent measurement of ventilatory parameters and respiratory gas exchange.

Clinical Exercise Testing

CET involves the measurement of respiratory gas exchange (oxygen uptake, carbon dioxide output, minute ventilation, and other variables) while monitoring the ECG, blood pressure, pulse oximetry (arterial oxygen saturation), and perceived exertion (Borg Scale) during a maximal symptom-limited incremental exercise test on a cycle ergometer or on a treadmill. In some circumstances, a constant workload exercise test (based on maximal test results) is performed. Measurement of arterial blood gases provides more detailed information on pulmonary gas exchange. Spirometry and exercise tidal flow-volume loops may also be performed to more accurately assess the degree of ventilatory constraint.

CET provides a global assessment of the integrative exercise responses, which are not adequately reflected by measurement of individual organ-system function at rest.¹⁵ As outlined above, the use of CET in clinical practice and patient management is increasing with the understanding that resting values cannot predict exercise performance and functional capacity. CET is safe, helps the clinician identify comorbidities, and can enhance understanding of and

insight into various responses, including exercise-limiting factors and therapeutic actions. Importantly, CET promotes an integrative approach to assessing metabolic, ventilatory, and cardiac function and reserve. Compared with simpler tests, it is technically more demanding, does not mimic daily activities (in most cases), and is more expensive. Peak oxygen uptake remains the gold standard for aerobic exercise capacity, especially important for impairment-disability evaluation and for preoperative evaluation.

CET has traditionally been undertaken with either an incremental stepwise or ramp protocol to exhaustion. However, constant-workload endurance exercise duration may be more responsive to detecting a treatment effect than other end points derived from exercise testing. In patients with COPD, the acute response to an inhaled bronchodilator was assessed using various types of exercise testing. The authors found that endurance time with a constant-workload exercise (80% of maximal work rate) was the most responsive end point to the effect of the bronchodilator among the exercise performance indices, showing a 19% improvement in exercise duration time. Conversely, the 6MWT distance improved by only 1% (Fig 1).¹⁶ Furthermore, arterial blood gases measured at minute 5 of constant-work exercise testing (based on 70% workload achieved during maximal CET, approximating 90 to 95% oxygen uptake max) may provide a practical and cost-effective alternative when arterial oxygen saturation, PaO₂, alveolar-arterial oxygen pressure difference, and the ratio of physiologic dead space to tidal volume are required.^{15,17}

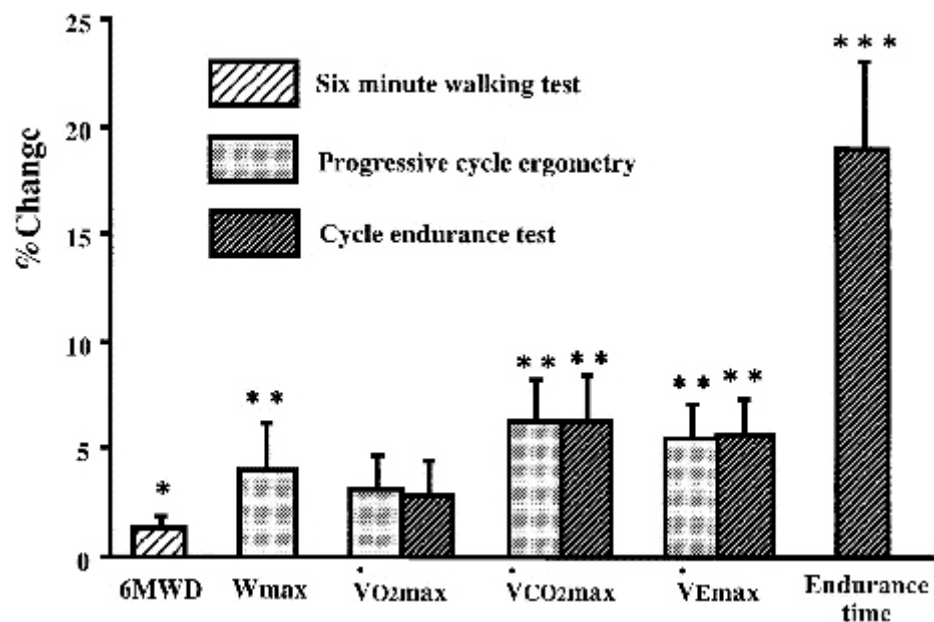


Figure 1. Changes in various measures of exercise performance after administration of oxitropium bromide in three exercise tests. Changes are expressed as the percent change from placebo. Values are expressed as mean \pm standard error. Wmax = maximal work capacity; V̇CO₂max = maximal carbon dioxide output; V̇Emax = maximal minute ventilation. *p<0.05, **p<0.01, ***p<0.001 vs placebo. Reprinted with permission from Oga et al.¹⁶

Clinical Indications for Exercise Testing

Specific indications for exercise testing are listed in Table 1, and discussed in detail elsewhere.^{2,15,18} It is readily apparent that the indications reflect usefulness in a broad spectrum of

clinical scenarios that affect all aspects of patient management and clinical decision making. Importantly, optimal clinical use of CET results is more likely when the interpretation reflects knowledge of all relevant patient information.

Table 1. Indications for Exercise Testing in Clinical Practice*

1. Evaluation of exercise intolerance
2. Evaluation of unexplained exertional dyspnea
3. Evaluation of patients with cardiovascular disease
 - Cardiomyopathy
4. Evaluation of patients with respiratory disease
 - COPD
 - Interstitial lung disease
 - Pulmonary vascular disease
 - Cystic fibrosis
5. Preoperative evaluation
6. Evaluation for transplantation (lung, heart, and heart-lung) and lung-volume reduction surgery
7. Exercise evaluation and prescription for pulmonary rehabilitation
8. Evaluation of impairment-disability

*Adapted from Weisman et al.¹⁸

The reader is encouraged to consult appropriate references^{2,3,14,15,18,19} regarding the methodology, quality assurance, reference values, conduct, and interpretation of CET results.

While significant progress has been made in our appreciation of the clinical application of exercise testing, further efforts to advance our understanding are needed.¹⁸ Questions remain about clinically meaningful differences, specific thresholds in defining abnormalities and severity, the clinical impact of a pattern-based approach to interpretation, specific protocols and testing methods, and the evolving role of novel techniques (*ie*, flow-volume curve analysis during exercise²⁰).

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