Serial Exercise Testing in Pulmonary Embolism*

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A patient underwent exercise testing during evaluation for unexplained dyspnea. Evidence of ventilation-perfusion mismatch was noted and subsequent testing revealed multiple pulmonary emboli. Ventilation perfusion parameters by serial exercise testing progressively improved during the course of the patient's illness but did not totally normalize.

In patients with pulmonary emboli, one of the primary pathophysiologic mechanisms is the development of abnormal gas exchange with mismatching of ventilation and perfusion.1 Recently, we had the opportunity to observe the usefulness of exercise testing, combined with arterial blood gas analysis, in helping us to establish a diagnosis of recurrent pulmonary emboli in a patient with unexplained dyspnea.

CASE REPORT

The patient was a 37-year-old ICU nurse who was four months postpartum, taking oral contraceptives and had smoked 20 pack-years. Prior to and following her delivery, she continued to work in the ICU, did her own housework, and cared for her two children, but was not involved in any regular, aerobic exercise program. Since her delivery, she had noticed the insidious onset of dyspnea on exertion and a "smoker's cough." She attributed her difficulty breathing to a 20-pound weight gain and smoking. Physical examination was not remarkable. Temperature was 37°C; pulse rate, 73 beats per minute; respiratory rate was 12 per minute; blood pressure, 90/70 mm Hg; weight, 80 kg; and height, 173 cm. The breath sounds and heart tones were normal.

The results of her initial pulmonary function and arterial blood gas studies were as follow: FVC, 3540 ml (87 percent), FEV1, 2820 ml (88 percent), FEV1/FVC, 80 percent; Dco; 17 ml/mm Hg/min (61 percent); pH, 7.41; PaO2, 88 mm Hg; PaCO2, 32 mm Hg; and HCO3, 20 mEq. These results were interpreted as "normal spirometry, reduced diffusing capacity suggesting an alveolar capillary defect, and a compensated respiratory alkalosis." A chest roentgenogram with PA and lateral views (Fig 1) showed clear lung fields and a normal sized heart. The resting 12-lead ECG was normal.

To further clarify the etiology of the unexplained dyspnea and decreased diffusing capacity in the presence of normal spirometry, stress testing was carried out on a cycle ergometer using a ramp slope of 25 watts min-1. The results of three serial exercise tests are shown in Figure 2. The first test (Aug 18, 1986) was stopped by the physician when he became concerned upon observing the development of 4 to 5 mm tall, peaked P waves on the ECG and a continuous fall in SaO2 (ear oximetry) greater than 5 percent from a baseline of 95 percent. The test was not continued to symptomatic maximum because of the potential danger of further exercise in a progressively hypoxicemic patient. At this point, the exercise was submaximal as evidenced by a drop in arterial bicarbonate of only 1 mEq and an "R" value below 1.00. The most remarkable findings were an O2 uptake of only 14 ml/kg/min at Wmax (maximal work rate), an abnormal anaerobic threshold of 39 percent (V O2 AT/ pred. V O2 max), and significant abnormalities in gas exchange manifested by mismatching of ventilation and perfusion (V/Q). The reduction in the patient's V O2 max put her in class "G" circulatory failure, according to the classification of Weber and Janicki.3 Upon comparing pre-exercise and Wmax values, the Vd/Vt rose from 0.43 to 0.47 (normal <0.25); the P(a-ET)CO2 increased from +7 mm Hg to +12 mm Hg (normal <0 at Wmax; and the P(A-a)O2 rose from 31 mm Hg to 52 mm Hg (normal 21 mm Hg). These abnormal results indicated increased dead space ventilation and were interpreted as being compatible with pulmonary vascular disease, ie, pulmonary emboli. A ventilation-perfusion lung scan (Fig 3) revealed multiple, mismatched, segmental perfusion defects, diagnosed as a "high probability" for pulmonary embolism.

The patient was started immediately on intravenous heparin and changed to oral warfarin sodium (Coumadin) in four days. At the

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A discussion of the utility of exercise testing in the evaluation of the patient with unexplained dyspnea is provided and the potential value of serial exercise testing in the management of patients with pulmonary emboli is discussed. (Chest 1988; 94:517-20)

Figure 1. PA chest film obtained during initial evaluation.
end of three months of anticoagulant therapy (Nov 25, 1986), a
repeat exercise test revealed a good metabolic response to exercise
with a 6 mEq drop in HCO₃⁻, a rise in "R" to 1.24, and a drop in
pH to 7.25, all indicating that the test was maximal. There was
significant improvement in maximal O₂ uptake to 21 ml/kg/min and
a rise in the anaerobic threshold to 49.6 percent; however, some
V/Q abnormalities persisted (Table 1). A second radionuclide lung
scan was obtained which likewise showed marked improvement,
but there were still several small, subsegmental perfusion defects.
Four months later (April 1, 1987), at which time the patient was
asymptomatic but still smoking, the V̇O₂max increased further to 26
ml/kg/min, while the anaerobic threshold held steady at 49.8
percent. Nevertheless, some V/Q mismatching remained, although
less striking than previously. This latter finding was felt to represent
partial, permanent impairment to the pulmonary circulation due to
a reduction in the vascular bed following embolization. The results
of follow-up tests in the pulmonary function laboratory were as
follows: FVC, 3,540 ml (88 percent); FEV₁, 2,790 ml (85 percent);
FEV₁/FVC, 79 percent; Dco, 26.8 ml/mmHg/min (94 percent);
pH, 7.45; PaO₂, 93 mm Hg; PaCO₂, 34 mm Hg; and HCO₃⁻, 23
mEq. Improvement was noted in the diffusing capacity from 61 to
94 percent.

**Discussion**

This case report represents an excellent example of the physiologic insights which can be gained by exercise testing combined with arterial blood gas analysis to measure gas exchange. The data obtained are useful in several ways, as follows: (1) to evaluate unexplained dyspnea; (2) to alert the physician of a ventilation-perfusion mismatch during exertion in the presence of normal spirometry; (3) to help direct the physician towards an early diagnosis of pulmonary embolism before the tragic consequences of irreversible pulmonary vascular occlusion occur; and (4) to follow the course of the disease and provide information of any residual damage or physical limitation for work.

Our laboratory is frequently consulted to evaluate patients with unexplained dyspnea. We have found Wasserman's diagnostic flow chart to be useful (Fig 4). In simple deconditioning, one will encounter a reduced V̇O₂max, lowered work capacity (V̇O₂max/ pred-V̇O₂max = <85 percent), low-normal anaerobic threshold (often in the range of 41 to 45 percent of the predicted V̇O₂max), and a reduced O₂/pulse at Wmax. It is important to note that the O₂/pulse (an index of stroke volume), although decreased in physical unfitness, has a normal, progressive rise during exercise. On the other hand, plateau formation or a fall in the O₂/pulse, along with a low value at maximal work rates, is indicative of cardiac dysfunction.

In pure cardiac disease with congestive failure, there is early onset of metabolic (lactic) acidosis without arterial O₂ desaturation. The usual findings are com-
FIGURE 3. Perfusion lung scan showing multiple segmented defects.

Combined low values in \( \dot{V}_{O_2} \)max, anaerobic threshold (below 40 percent), and \( O_2/ \)pulse. Often the heart rate reserve (\( 1-[HR_{max}/predHR_{max}] \)) is low or absent (rapid heart rate) at the end of a symptom-limited test. The ECG or blood pressure may indicate coronary artery or hypertensive disease, respectively. A fall in systolic blood pressure, in the face of a rising work rate, is a strong indicator of left ventricular dysfunction and necessitates that the exercise be stopped promptly.

In significant obstructive or restrictive (interstitial)

**Figure 4. Diagnostic flow chart.**
lung disease, the breathing reserve (1 - $\dot{V}_{\text{Emax}}/\text{MVV}$) is characteristically limited (below 30 percent) at Wr max; and the respiratory rate, especially in pulmonary fibrosis, is frequently increased above 50 breaths/min. The $V/Q$ parameters also are affected in these disease states, as well as in pulmonary vascular disease and pulmonary hypertension. In addition, there may be evidence of pump dysfunction if there is increased pressure from the pulmonary circuit on the right ventricle. The development of peaked "P" waves during stress is indicative of exercise-induced pulmonary hypertension secondary to a reduction in the pulmonary vascular bed. Traditionally, pulmonary embolism and pulmonary hypertension have been considered as contraindications to stress testing. Certainly, exercise testing is not the proper diagnostic approach in patients who are suspected to have an acute pulmonary embolus! In similar instances, our practice is to immediately obtain a ventilation-perfusion lung scan. Regarding pulmonary hypertension, D’Alonzo and colleagues performed progressive exercise testing in 11 patients with primary pulmonary hypertension (mean pulmonary artery pressure of 33 mm Hg or higher) without serious sequelae. Also, Janicki et al tested five patients, two with pulmonary emboli and three with primary pulmonary hypertension (mean pulmonary artery pressure at rest of 55 ± 6 mm Hg) without adverse after effects. We believe that with careful patient selection and monitoring of the pulse, blood pressure, ECG and SaO₂%, progressive exercise testing does not pose an undue risk to such patients.

In summary, we routinely obtain a ventilation/perfusion lung scan in patients with unexplained dyspnea and evidence of $V/Q$ abnormalities on exercise testing. Our primary test is to rule out recurrent, small pulmonary emboli, and if possible, prevent irreversible pulmonary vascular damage. Furthermore, as our patient demonstrates, the addition of serial exercise testing, with measurement of gas exchange ($P[A-a]O₂$, $P[a-ET]CO₂$ and $Vd/Vt$) is a useful functional index of the status of the pulmonary microcirculation and may alert one to the possibility of unresolved or recurrent “silent” small emboli to the lungs.

REFERENCES