Predictive accuracy of criteria used to assess maximal oxygen consumption

To evaluate criteria frequently used to designate an exercise test as maximal, 33 men and 18 women completed progressive incremental cycle ergometry to exhaustion with direct measurement of oxygen consumption (VO₂). On a separate day, subjects exercised at 115% of the maximal work rate attained in the first test following a 5-minute warm-up. If VO₂ exceeded that of the progressive test by ≥150 ml/min, subjects returned on a third day and pedalled at 125% of the first day's work rate (peak). This procedure was repeated until VO₂ increased <150 ml/min, and defined whether the progressive test was a maximal or nonmaximal test. There were 45 tests that met the criterion for maximum during the progressive test and six nonmaximal tests. Respiratory exchange ratio and 85% age-predicted maximal heart rate were sensitive criteria for a maximal test but were not specific. Attainment of age-predicted maximal heart rate and peak lactate >8 mmol/L were highly specific but insensitive measures of a maximal test. In the absence of a VO₂ plateau, age-predicted maximal heart rate and lactate >8 mmol/L can be used as indicators of maximal tests with a high degree of confidence. When age-predicted maximal heart rate or lactate >8 mmol/L are not attained, the test may still be maximal because negative predictive value is low. (AM HEART J 1992;123:922.)

Nina S. Stachenfeld, MA, Mark Eskenazi, BS, Gilbert W. Gleim, PhD, Neil L. Coplan, MD, and James A. Nicholas, MD, New York, N.Y.

Maximal oxygen consumption (VO₂max) is the most widely used index of aerobic fitness and is used to measure responses to training. The gold standard for assessment of VO₂max is attainment of an oxygen consumption plateau (VO₂P). The attainment of VO₂P during increasing work suggests that maximal cardiac output and maximal oxygen extraction have been attained and that a healthy individual has reached the limits of his or her circulatory and respiratory capacity. However, the frequency that VO₂P is attained depends on how VO₂P is defined, the exercise protocol and the modality used, and the population tested. Different investigators have reported the incidence of VO₂P in 17% to 98% of exercise tests.

In the absence of a clearly defined VO₂P, other criteria have been used to determine if a test is maximal. These criteria include the attainment of a Respiratory Exchange Ratio ≥1.10 (RER 1.10), Respiratory Exchange Ratio ≥1.15 (RER 1.15), 5-minute postexercise venous lactate ≥8.0 mmol/L, and attainment of age-predicted maximum heart rate (APMHR). Although these criteria are frequently used in the literature to evaluate a maximal effort, they have not been studied as to how they specifically relate to attainment of VO₂P. The purpose of the present study was to examine the predictive accuracy of RER 1.10, RER 1.15, postexercise lactate, and APMHR with respect to the attainment of maximal exercise as defined by reaching an oxygen consumption plateau. Since attainment of 85% age-predicted maximal heart rate is used as an end point in some diagnostic stress tests, the predictive accuracy of this criterion was also evaluated.

METHODS

Subjects. Eighteen women and 33 men participated in this investigation (Table I). Subjects had no known cardiac or pulmonary disease. Each subject was informed as to the experimental procedures, completed a medical history, and signed informed consent statements in accordance with the guidelines of the Human Investigation Committee at Lenox Hill Hospital.

Experimental design. All testing was performed within a 2-week period on separate days. On day 1, subjects performed an incremental test to exhaustion on a Fitton cycle
ergometer (Lumex Corp., Ronkonkoma, N.Y.). Work was increased 100 or 150 kilopond-meters (kpm) every minute depending on body size. Oxygen consumption was continuously measured with 20-second averaging by a SensorMedics 2900 or MMC Horizon measurement cart (SensorMedics Corp., Yorba Linda, Calif.). All tests for each subject were done with the same machine. Heart rate was monitored continuously with three leads by a SensorMedics Horizon electrocardiograph (ECG) (SensorMedics Corp.). The subjects continued cycling until they could no longer maintain their work rate. The investigators were aware of VO2 and heart rate (HR) during the test; however, the subjects were encouraged to continue regardless of the values. Five minutes after the test, 37 of the subjects had forearm blood drawn nonischemically with a tuberculin syringe for blood lactate determination. Lactate was assayed with a YSI model 23L lactate analyzer (YSI Inc., Yellow Springs, Ohio) within 5 minutes of venipuncture.

On day 2, subjects warmed up for 2 minutes at 30% and then for 3 minutes at 50% of the peak work rate from day 1. Warm-up intensity was increased if heart rate did not reach 150 beats/min. Warm-up was followed by exercise at 115% of peak work rate from day 1 for at least 80 seconds. If VO2peak on day 2 did not exceed that of day 1 by >150 ml/min, the test on day 1 was considered to be maximal. If peak VO2 on day 2 exceeded peak VO2 from day 1 by ≥150 ml, the test on day 1 was not considered maximal and the subject returned for a third test. The third test included a 5-minute warm-up as on day 2, after which the subject exercised at 125% of peak work rate from day 1. If the subject continued to increase VO2peak by >150 ml/min, the tests were repeated, increasing exercise work rate by 10% until the increase in VO2peak from the previous test did not exceed 150 ml/min. Increases in VO2peak by 150 ml/min were chosen a priori based on The American College of Sports Medicine’s calculation that an increase in 100 kpm should elicit an increase of 200 ml/min, and all increments during the initial test were at least 100 kpm/min and none were greater than 150 kpm/min.

Statistical analysis. Surpassing of the following criteria during the first test was assessed as being either positive or negative (Fig. 1): RER ≥1.10 (RER1.10); RER ≥1.15 (RER 1.15); lactate ≥8.0 mmol/L (LAC8); HR ≥ age-predicted maximal heart rate (APMHR), defined as 220-age15; and 85% APMHR ≥85% age-predicted maximal heart rate (85 APMHR).

RESULTS

VO2peak was defined as the highest VO2 attained on day 1 and VO2max was the maximal oxygen consumption attained on the test that met the leveling-off criteria. Eighty-eight percent of the subjects attained VO2peak on the day 1 test. The mean VO2peak on day 1 (3.28 L/min) differed significantly (p < 0.05) from the mean VO2max (3.35 L/min), although the difference was less than 150 ml/min. Six subjects (12%) surpassed the first test VO2peak on subsequent tests by ≥150 ml/min.

The sensitivity of RER 1.10, RER 1.15, and 85
Sensitivity = \[
\frac{\text{True Max}}{\text{True Max} + \text{False Non-Max}}
\]

Specificity = \[
\frac{\text{True Non-Max}}{\text{True Non-Max} + \text{False Max}}
\]

Positive Predictive Value = \[
\frac{\text{True Max}}{\text{True Max} + \text{False Max}}
\]

Negative Predictive Value = \[
\frac{\text{True Non-Max}}{\text{True Non-Max} + \text{False Non-Max}}
\]

Fig. 2. Formulas for sensitivity, specificity, and positive and negative predictive values. Max, Maximal.

Table II. Sensitivity, specificity, positive (PPV) and negative (NPV) predictive values of the criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>PPV (%)</th>
<th>NPV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RER 1.10</td>
<td>100</td>
<td>0</td>
<td>88</td>
<td>0</td>
</tr>
<tr>
<td>RER 1.15</td>
<td>82</td>
<td>17</td>
<td>82</td>
<td>11</td>
</tr>
<tr>
<td>APMHR</td>
<td>25</td>
<td>83</td>
<td>92</td>
<td>13</td>
</tr>
<tr>
<td>85 APMHR</td>
<td>44</td>
<td>0</td>
<td>88</td>
<td>0</td>
</tr>
<tr>
<td>LAC8</td>
<td>25</td>
<td>100</td>
<td>100</td>
<td>5</td>
</tr>
<tr>
<td>APMHR + RER 1.15</td>
<td>44</td>
<td>100</td>
<td>100</td>
<td>5</td>
</tr>
<tr>
<td>APMHR + LAC8</td>
<td>22</td>
<td>83</td>
<td>91</td>
<td>13</td>
</tr>
<tr>
<td>APMHR + RER 1.15 + LAC8</td>
<td>0</td>
<td>100</td>
<td>100</td>
<td>5</td>
</tr>
<tr>
<td>APMHR + RER 1.15 + LAC8</td>
<td>36</td>
<td>100</td>
<td>100</td>
<td>4</td>
</tr>
<tr>
<td>LAC8 + RER 1.15</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td>LAC8 + 85 APMHR</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>5</td>
</tr>
<tr>
<td>LAC8 + RER 1.15 + 85 APMHR</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>5</td>
</tr>
</tbody>
</table>

APMHR were in excess of 80%; the specificity of each of these criteria were all below 20%. In contrast, APMHR had low sensitivity (25%) and high specificity (83%). LAC8 had a sensitivity of 44% and a specificity of 100% (Table II). The addition of APMHR or 85 APMHR to LAC8, RER 1.10 or RER 1.15 reduced the sensitivity of each parameter used independently. LAC8 added to RER 1.15 improved specificity (Table II). The positive predictive value of each parameter examined was greater than 80%, while the negative predictive values were below 20% (Table II).

DISCUSSION

Most of the subjects who attained VO2max during the day 1 test attained or exceeded RER 1.10, RER 1.15, and 85 APMHR, but these criteria were also likely to be attained during a nonmaximal test. Peak RER 1.10, RER 1.15, and 85 APMHR are therefore not stringent enough to distinguish a maximal from a nonmaximal test.

In contrast, the high specificity of achieving APMHR makes it a very stringent criteria for VO2max, but the low sensitivity indicates that many subjects who reached max on day 1 did not attain APMHR. The higher sensitivity of LAC8 (44%) combined with its 100% specificity, make LAC8 a better overall test than APMHR.

In the present investigation, we defined VO2max as when a work rate increase of 15% (average of 227 kpm increase) resulted in a VO2 difference of less than 150 ml/min. This definition was derived empirically by Taylor et al.,12 and as such is not a gold standard. In addition, the 200 ml/min per 100 kpm work increase suggested by the American College of Sports Medicine is a predicted response and can vary between individuals. Because of the lack of a gold standard, any test of sensitivity or specificity for VO2max testing is inherently flawed. Nevertheless, the >150 ml/min criterion cited in the literature as stan-

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References 1, 6, 7, 9, 11, and 12.  
References 1, 2, 6, 8, 9, 14, and 17.  
References 2, 6, 8, 9, 12, and 14.  

References


