# Using Exercise Respiratory Measurements to Compare Methods of Exercise Prescription

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**Exercise heart rate (HR) ranges based on peak HR, age-predicted maximal HR and peak oxygen consumption were compared to determine which method is most likely to result in an exercise prescription within guidelines determined from exercise respiratory measurements (upper limit—ventilatory threshold; lower limit—50% peak oxygen consumption). Exercise prescriptions based on either 80% peak HR or 70% peak measured oxygen consumption were significantly more likely to be within these guidelines ($p < 0.05$) than other criteria tested; there was no significant difference between these 2 methods. Recommended exercise intensity based on 85% peak HR and 80% peak oxygen uptake resulted in a large percentage of patients with a heart rate above the ventilatory threshold (46% and 54%, respectively), whereas target HR derived from 75% peak HR and 60% peak oxygen consumption resulted in many patients with a heart rate below the lower limit (38% and 42%, respectively). Exercise prescription based on predicted maximal HR was of little value, regardless of the percentage used to determine target heart rate. The best methods identified in this study yielded an exercise intensity exceeding ventilatory threshold 15 to 20% of the time. Exercise prescription based on direct assessment of the ventilatory threshold is therefore preferred.**

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Recommendations from the American Heart Association[1,2] and the American College of Sports Medicine[3] for determining exercise intensity are based on a percentage of maximal heart rate (HR) or oxygen consumption. The criteria are designed so that training will result in an aerobic conditioning effect (increase in maximal oxygen consumption and reduced HR at submaximal exercise). Several indexes can be used, however, and the optimal method is controversial.

Respiratory measurements during exercise can be used to provide guidelines for evaluating an exercise prescription.[4] Exercise above the ventilatory threshold, identified by a nonlinear rise in minute ventilation with respect to oxygen consumption, is correlated with an abrupt rise in venous lactate[5,6]; exercise in excess of this point is associated with a reduced exercise tolerance[5-7] and a neurohumoral pressor response.[8-10] Exercise below 50% peak oxygen consumption is unlikely to result in significant aerobic training effect.[11-13] The purpose of the present study was to use exercise respiratory variables to identify the exercise prescription method most likely to incorporate this information.

## Methods

**Patients:** Fifty healthy subjects (48 men, 2 women) referred for a fitness evaluation were studied. The patients were 22 to 69 years old (mean 44 ± 11). They were not taking medication and had neither symptoms nor a history of cardiovascular disease.

**Exercise test:** Subjects fasted for at least 8 hours before testing and performed an exercise test to volitional fatigue on a motorized treadmill (Bruce protocol).[14] HR and ectopic activity were continuously monitored and a 12-lead electrocardiogram was recorded before the end of each stage. Ventilatory and gas exchange measurements were measured with a SensorMedics® metabolic measurement cart calibrated with

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**TABLE I Exercise Ranges for a 40-Year-Old Patient with Peak Exercise Heart Rate of 200 Beats Per Minute**

| Method 1 (% Peak Measured HR) | | | Method 2 (HR at % Peak Measured $VO_2$*) | | | Method 3 (% Predicted Peak HR) | | |
|---|---|---|---|---|---|---|---|---|
| % | THR | ER | % | THR | ER | % | THR | ER |
| 85% | 170 | 160–170 | 80% | 170 | 160–170 | 85% | 153 | 143–153 |
| 80% | 160 | 150–160 | 70% | 160 | 150–160 | 80% | 144 | 134–144 |
| 75% | 150 | 140–150 | 60% | 150 | 140–150 | 75% | 135 | 125–135 |

* The heart rates at % peak $VO_2$ are obtained from the graph of heart rate vs $VO_2$, as in Figure 1.

ER = exercise range; HR = heart rate; THR = target HR; $VO_2$ = oxygen consumption.

**TABLE II Comparison of Patients Based on American College of Sports Medicine Cardiorespiratory Fitness Levels[3]**

| Level ($PVO_2$) | n | Age* | Time† | $PVO_2$† | VTh/PHR* |
|---|---|---|---|---|---|
| Average‡ (25–39) | 21 | 49 ± 11 | 10 ± 2 | 32 ± 5 | 84 ± 5 |
| Good (39–49) | 19 | 42 ± 10 | 13 ± 1 | 44 ± 3 | 84 ± 7 |
| High (49–56) | 10 | 40 ± 7 | 15 ± 1 | 53 ± 5 | 87 ± 5 |

* No significant difference between any group; † $p < 0.05$ for comparison with each group. ‡ Includes 3 patients with $PVO_2$ of 24–25 ml/kg/min.

Values are mean ± standard deviation.

n = number of patients in each category; $PVO_2$ = peak oxygen consumption (ml/kg/min); time = duration of exercise in minutes; VTh/PHR = % peak heart rate at which ventilatory threshold occurs.

gases spanning a range of 0 to 4% $CO_2$ and 0 to 16% $O_2$ (Scientific Gas Products). Ventilatory measures were averaged over 15-second intervals.

**Determination of exercise range (Table I):** Nine target heart rates were derived for each subject, based on the peak HR during exercise, peak measured oxygen consumption during exercise and age-predicted maximal HR (220 − age): 1 to 3—85%, 80% and 75% of peak measured HR; 4 to 6—HR at 80%, 70% and 60% peak measured oxygen consumption; and 7 to 9—85%, 80% and 75% of age-predicted maximal HR. Each target HR was then used to determine an exercise range, defined as the range from target HR to 10 beats below target HR. For example, a target HR of 170 beats/min leads to an exercise range of 160 to 170 beats/min. An exercise range was used because it is more practical for a patient monitoring his pulse to exercise within a range than to a specific target HR.

**Respiratory limits:** HR at ventilatory threshold and HR at 50% peak oxygen consumption were used as upper and lower limits, respectively, with which to compare the exercise ranges. Both respiratory limits were derived from a graph of measured oxygen consumption vs heart rate and minute volume (Fig. 1). Ventilatory threshold was defined as the point where there is a nonlinear increase in minute volume compared with oxygen consumption, a method shown to correlate well with lactate threshold.[5,15] The mean difference between HR at ventilatory threshold and 50% peak oxygen consumption was 32 ± 10 beats/min.

**Comparison:** For each subject, the 9 exercise ranges were compared with the range between HR at ventilatory threshold and HR at 50% peak oxygen consumption. Chi-square analysis was used to compare

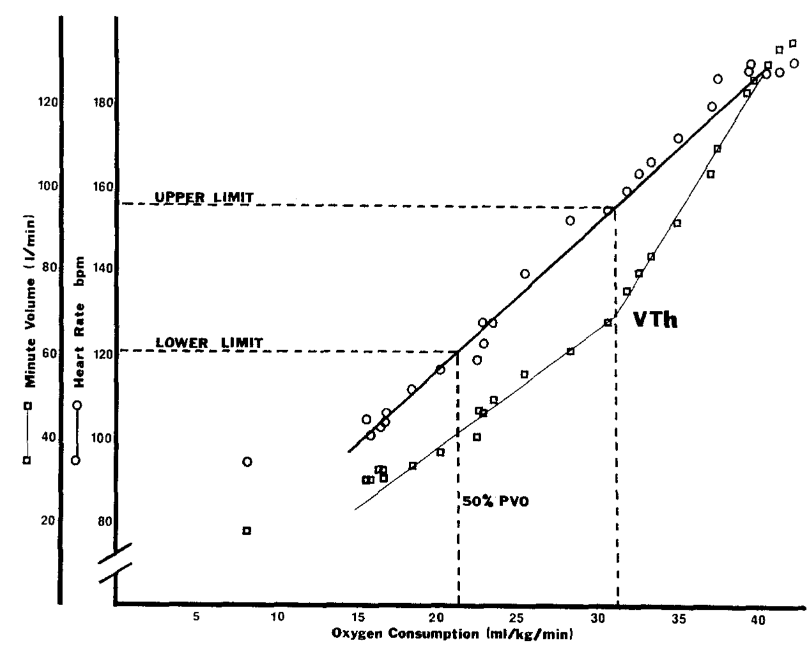


**FIGURE 1. Determination of heart rate corresponding to ventilatory threshold (VTh) and 50% peak oxygen consumption (PVO). The ventilatory threshold (upper limit) is located where a nonlinear rise in minute ventilation with respect to oxygen consumption occurs during progressive exercise; the corresponding heart rate and oxygen consumption at ventilatory threshold can be determined from this graph (upper limit). The heart rate at 50% PVO (lower limit) is determined by drawing a vertical line from the relevant point on the abscissa to the heart rate line.**

**TABLE III Comparison of Maximal* and Submaximal Tests**

| | Maximal Test (n = 10) | Submaximal Test (n = 40) |
|---|---|---|
| Age | 48 ± 11 | 44 ± 10 |
| PHR | 171 ± 19 | 176 ± 20 |
| $HR_{VTh}$ | 147 ± 21 | 148 ± 20 |
| $HR_{VTh}$/PHR | 86 ± 7 | 84 ± 5 |
| $PVO_2$ | 40 ± 9 | 41 ± 10 |
| $VO_2VTh$ | 32 ± 7 | 31 ± 7 |
| $VO_2VTh/PVO_2$ | 80 ± 6 | 76 ± 7 |

* Criteria for maximal test = more than 10-liter/min increase in minute ventilation for 100-ml/min oxygen consumption at peak measured oxygen consumption.

Values are mean ± standard deviation.

$HR_{VTh}$ = heart rate at ventilatory threshold; $HR_{VTh}$/PHR = % peak heart rate at which ventilatory threshold occurs; PHR = peak heart rate; $PVO_2$ peak measured oxygen consumption (ml/kg/min); $VO_2VTh$ = oxygen consumption at which ventilatory threshold occurs; $VO_2VTh/PVO_2$ = % peak oxygen consumption at which ventilatory threshold occurs.

**TABLE IV Comparison of Exercise Heart Rate Range Based on Peak Measured Heart Rate**

| Target Heart Rate Based on: | 85% PHR | 80% PHR | 75% PHR |
|---|---|---|---|
| No. of pts with exercise heart rate | | | |
| Within limits | 26* | 39 | 28† |
| >VTh | 23 | 10 | 3 |
| <50% $PVO_2$ | 1 | 1 | 19 |

* $p < 0.02$ compared to 80% PHR; † $p < .05$ compared to 80% PHR.

PHR = peak measured heart rate; $PVO_2$ = peak oxygen consumption; VTh = ventilatory threshold.

**TABLE V Comparison of Exercise Heart Rate Range Based on Peak Measured Oxygen Uptake**

| Target Heart Rate Based on: | 80% $PVO_2$ | 70% $PVO_2$ | 60% $PVO_2$ |
|---|---|---|---|
| No. of pts with exercise heart rate | | | |
| Within limits | 23* | 42 | 29* |
| >VTh | 27 | 5 | 0 |
| <50% $PVO_2$ | 0 | 3 | 21 |

* $p < 0.01$ compared to 70% $PVO_2$.

$PVO_2$ = peak oxygen consumption; VTh = ventilatory threshold.

the number of subjects from each method with an exercise range within the respiratory limits.

Group values are reported as mean ± standard deviation. HR refers to measured HR during exercise, unless predicted HR is specifically indicated. All oxygen consumption values refer to measured oxygen consumption.

## Results

**Exercise test:** Average duration of exercise was 12 ± 3 minutes and mean peak oxygen consumption was 40 ± 9 ml/kg/min (range 24 to 66). Ventilatory threshold occurred at 148 ± 20 beats/min, representing 85 ± 6% of peak HR during the exercise test. One-way analysis of variance revealed that fitness level,[3] based on peak oxygen consumption, had no effect on percentage of peak exercise HR at ventilatory threshold (Table II).

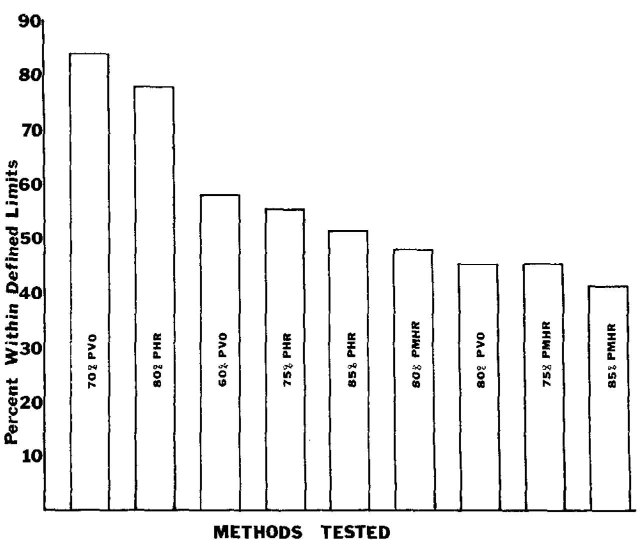


**FIGURE 2. Percentage of patients within respiratory limits (ventilatory threshold and 50% peak oxygen consumption) from each method of determining target heart rate. PHR = peak heart rate during exercise; PMHR = predicted maximal heart rate; PVO = peak measured oxygen consumption.**

Measured maximal HR exceeded 85% of age-predicted maximal HR in 96% of subjects. Subjects with maximal and submaximal tests by a respiratory leveling-off criteria were similar with respect to exercise variables (Table III), and all patient data were pooled and termed "peak" for further analysis.

**Exercise range based on measured peak heart rate (Table IV):** An exercise HR range based on 85% measured peak HR resulted in 46% of patients exercising above the ventilatory threshold. Six percent exceeded ventilatory threshold if 75% peak HR was used, but 38% of the group fell below the heart rate corresponding to 50% peak oxygen uptake. Significantly more patients (78%) had an exercise HR range between ventilatory threshold and 50% peak oxygen uptake for target HR based on 80% measured peak HR.

**Exercise range based on percentage peak oxygen uptake (Table V):** The exercise HR range for 46% of the subjects exceeded ventilatory threshold when 80% peak oxygen uptake was used for determining target HR. No patient exceeded ventilatory threshold at 60% peak oxygen uptake, but 42% had an exercise range below the lower limit. Significantly more patients (84%) had an exercise HR range within the respiratory limits if 70% peak oxygen uptake was used determine target heart rate.

**TABLE VI Comparison of Exercise Heart Rate Range Based on Predicted Maximal Heart Rate**

| Target Heart Rate Based on: | 85% PMHR | 80% PMHR | 75% PMHR |
|---|---|---|---|
| No. of pts with exercise heart rate | | | |
| Within limits | 21 | 24 | 23 |
| >VTh | 27 | 17 | 9 |
| <50% $PVO_2$ | 2 | 9 | 18 |

PMHR = predicted maximal heart rate; $PVO_2$ = peak oxygen consumption; VTh = ventilatory threshold.

There was no significant difference between the number of patients with exercise HR range within the respiratory limits when the results of target HR based on 80% maximal heart rate and 70% peak oxygen uptake were compared.

**Exercise range based on predicted maximal heart rate (Table VI):** There was no significant difference between the number of patients with an exercise HR range within limits when 85%, 80% or 75% of predicted maximal HR were used to determine target HR. All of these criteria resulted in over 50% of patients outside the guidelines, and were significantly less effective than the range based on 80% peak measured HR or 70% peak oxygen consumption ($p < 0.01$).

## Discussion

HR at ventilatory threshold and 50% peak oxygen consumption were used as upper and lower limits with which to compare methods of determining exercise intensity. The 2 criteria that yielded the greatest number of subjects falling within this range were 80% peak measured HR and the HR at 70% peak measured oxygen consumption (Fig. 2). The other indexes were significantly more likely to result in an exercise range that exceeded the subject's ventilatory threshold or went below the HR at 50% peak oxygen consumption. An exercise prescription based on any percentage of age-predicted maximal HR resulted in 50% of subjects falling outside the respiratory limits, indicating this was the least preferable method tested.

There was no significant difference between 80% peak measured HR and 70% peak oxygen consumption with respect to the number of patients with an exercise range within respiratory limits. The former is the preferred parameter because it is more easily determined and more accurate when respiratory measurements are not available.[16-21] The exercise HR range derived from 80% peak measured HR and the HR at 70% peak oxygen consumption exceeded ventilatory threshold 15 to 20% of the time. Therefore, exercise prescription based on direct assessment of ventilatory threshold is recommended when possible.

**Respiratory guidelines:** Ventilatory threshold was chosen as the upper limit because it is a correlate of lactate threshold.[5,6,15] Plasma catecholamine and renin levels both begin to rise at the lactate threshold,[8-10] a response that may have deleterious consequences for patients with arrhythmia, hypertension, coronary artery disease or heart failure. Indirect evidence suggests that exercise above the lactate threshold is associated with exertion-related mortality. A review[22] of 15 cases of sudden death during cardiac rehabilitation showed that 9 of the patients were exercising in excess of 85% of peak HR, and thus were likely to have been at an exercise intensity above lactate threshold. In addition, the ability to perform sustained exercise is limited above the lactate threshold.[5-7]

The minimal training intensity needed to produce a demonstrable training effect is influenced by a person's activity pattern before starting exercise and the duration of exercise.[11,13,23] Although it is unlikely that there is an absolute training threshold below which no training occurs, there is little improvement in maximal oxygen consumption for training intensities below 50% maximal oxygen consumption.[11-13]

**Clinical implications:** These results apply to the large group of subjects without a history of cardiac disease who present for advice about exercise intensity. Patients with a history of coronary artery disease were not included in the study, but it seems reasonable to extend our approach to patients in stable condition who do not show evidence of myocardial ischemia during the exercise test. The method may be less useful for patients with angina or ischemic electrocardiographic changes during exercise, in whom exercise prescription can be guided by the heart rate at which these responses occur.[1]

The study group did not include patients who were taking medications that affect heart rate, and the results may not be applicable to such patients.[24] Further study is needed to assess the relation between heart rate and ventilatory threshold in patients taking this type of medication. In addition, whether the same results would be obtained by testing with a different protocol or exercise method (e.g., bicycle ergometer) is speculative.

In conclusion, exercise respiratory measurements provide a framework to assess the results of exercise prescription. When available, exercise prescription should be based on direct assessment of ventilatory threshold. The preferred method to use when respiratory measurements are not available is an exercise range based on 80% peak measured HR.

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