Evaluation of a New Treadmill Exercise Protocol*

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Study objectives: To confirm that a newly drafted treadmill exercise protocol designed on a theoretical basis to span a range of 0 to 200 W with approximately 25-W increments by alteration of either speed or grade from one stage to the next should correspond to a standard bicycle protocol consisting of 25-W steps.

Design: Randomized, crossover study to compare both exercise test modes.

Study participants: Twenty-one consecutive healthy volunteers.

Interventions: Subjects underwent both exercise tests until either exhaustion or completion of the respective protocol, and cardiopulmonary exercise parameters were assessed during either of them. For comparison, correlation coefficients (r) were calculated.

Results: Exercise tolerance time was 9% higher on the treadmill (p<0.05). Ten subjects completed the bicycle program, whereas 18 subjects did so on the treadmill. With both protocols, there were comparably linear increases in heart rate (r=0.885), oxygen uptake (r=0.925), oxygen uptake per body weight (r=0.944), carbon dioxide output (r=0.937), and minute ventilation (r=0.914). For the 2-min stage duration, a plateau in oxygen uptake was achieved with neither protocol. The ventilatory equivalent for oxygen, which is not linear, showed its minimum at comparable workloads, at the point of surpassing anaerobic threshold. Correlation of oxygen pulse was fair (r=0.896).

Conclusions: There was an excellent correlation of the parameters with respect to both measured values at identical workloads and slopes of both protocols, thus enabling comparability of treadmill and bicycle ergometry. Due to its practical handling, the new protocol may facilitate acceptance, especially when used for elderly or disabled patients.

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Key words: bicycle ergometry; cardiopulmonary exercise testing; treadmill protocol

Abbreviations: HR=heart rate; r=correlation coefficient; VCO2=carbon dioxide output; VO2/VCO2=respiratory quotient; VE=minute ventilation; VE/VCO2=ventilatory equivalent for oxygen; VO2=oxygen uptake

As a noninvasive method, cardiopulmonary exercise testing is primarily used to identify the mechanism of effort intolerance, of which pulmonary vascular disorders, obstructive or restrictive lung diseases, heart diseases, obesity, metabolic or muscular disorders, hemoglobinopathies, and chest wall defects are the most important. Furthermore, this method is applied for graduation of heart failure, for assessment of the response to medical or surgical therapy, eg, heart valve repair or replacement, or the preferred mode of pacing for exercise training or, as in the case of preoperative treatment decisions such as cardiac transplantation, for patient selection.9,10 For this, treadmill and bicycle ergometry represent the most important methods, both of which serve the purpose of differentiating disorders of the cardiopulmonary system from inadequate effort, obesity, anxiety, or unfitness.1 The choice of method is based predominantly on familiarity and experience while taking into consideration the ease of quantitating workload and obtaining additional parameters such as arterial blood samples, safety, and lastly, costs.1 Because of their inherent differences, the two methods are difficult to compare. Nevertheless, a comparison would appear desirable to enable reference of a measured parameter to a well-defined workload for scientific evaluation or, for a given patient, to facilitate comparability of exercise tests carried out on different devices during routine applications.

Since mere level walking without an uphill grade-
ent already leads to increases in heart rate (HR), BP, oxygen uptake (VO₂), and cardiac output, it is not correct to interpret an incremental treadmill exercise test as simple graded work.11 Thus, parameters are needed to reflect cardiac output as a measure of cardiac work that should be identical at comparable workloads. HR, which according to Fick’s principle closely parallels cardiac output,1,12-14 is strongly dependent on the age of the patient, stroke volume, body temperature and familiarity with the mode of exercise testing.12,15-17 Consequently, it is subject to such extensive variability that comparability is precluded. The use of BP-HR product to reflect myocardial oxygen consumption18-20 must be regarded similarly since it is dependent on the HR again. Thus, because of its correlation with cardiac output, VO₂ forms the basis for comparisons such that identical workloads should lead to an identical cardiac output.5,21

Accordingly, it was the aim of the present study to relate a given treadmill stage to a well-defined workload on the bicycle ergometer on the basis of VO₂ measurements. A new treadmill exercise protocol was designed, appropriate for clinical use in patients with heart disease spanning the range of their everyday activities.12 The protocol is intended to avoid both an excessive duration1,12,23 and excessive workload increments, which may be the case with many of the protocols currently in use24-27 since otherwise achievement of higher workloads or even of a plateau in VO₂ will often be missed, especially in elderly patients who frequently suffer from concomitant illnesses28,29. Finally, since patients with any kind of heart disease are likely to be older and, consequently, are often disabled with respect to mobility and muscular coordination, the new protocol was designed to change only either speed or grade from one stage to the next alternately in order to facilitate coordination of motion during exercise.

### Materials and Methods

#### Subjects

Twenty-one subjects volunteered for this study. All carried out some type of light physical activity such as bicycle riding during their leisure time, but were not highly trained for competitive sports. There were 10 women (mean age, 25 years; range, 21 to 39 years) and 11 men (mean age, 26 years; range, 23 to 32 years). The average height was 176±10 cm (SD) and the average weight was 69±12 kg. No subject had known disease of the cardiovascular or respiratory system or any impairment of muscular or skeletal mobility. None was taking medication regularly. Informed consent was obtained from all subjects prior to the studies according to the protocol approved by the Ethics Committee of the Klinikum rechts der Isar.

#### Study Protocols

There were two different protocols using either the bicycle or the treadmill, both of which were applied to every participating subject in a randomized order (Table 1). Exercise tests were always carried out in the morning after at least 2 h of fasting. Repeated testing was performed after an interval of between 3 h and 1 day. The subjects were encouraged to complete the entire range of both protocols, ie, up to 200 W at each testing.

Bicycle testing was performed on a revolution/minute-independent ergometer (Ergo-Metrics 800 S; Ergo-Line; Bitz, Germany) with increments of 25 W every 2 min until exhaustion or 200 W had been reached.

The treadmill (Laufgerotest-Junior; Erich Jaeger GmbH; Wuerzburg, Germany) program had been designed such that, on a basis of an average body weight of 75 kg, each 2-min stage would correspond to a calculated increment of 25 W. The metabolic cost of walking at a given speed and grade was calculated according to both the equation of Givoni and Goldman30 and the nomogram published by Astrand and Ryhming,31 referencing a given work level to oxygen intake. The equation of Givoni and Goldman30 expressed in kilocalories per hour was converted to VO₂ per hour by assuming a metabolic equivalent of 4.9 kcal/1,000 mL oxygen for a standard diet consisting of about 50% carbohydrates, 30% fat, and 20% protein.32

Exercise and gas exchange data were collected continuously using an automated breath-by-breath system33 (CPX-D Series 2) based on manufactured methods (Medical Graphics Corporation; St. Paul, Minn). A clamp is placed on the nose and the patient

### Table 1—Comparison of Protocols*

<table>
<thead>
<tr>
<th>Stage</th>
<th>Bicycle W</th>
<th>VO₂ mL/min</th>
<th>Treadmill Speed, km/h</th>
<th>Grade, %</th>
<th>VO₂ kg/L/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25</td>
<td>650</td>
<td>3.2</td>
<td>0</td>
<td>8.5</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>950</td>
<td>3.2</td>
<td>6</td>
<td>13.0</td>
</tr>
<tr>
<td>3</td>
<td>75</td>
<td>1,250</td>
<td>4.2</td>
<td>6</td>
<td>17.5</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>1,550</td>
<td>4.2</td>
<td>10</td>
<td>21.5</td>
</tr>
<tr>
<td>5</td>
<td>125</td>
<td>1,850</td>
<td>4.5</td>
<td>10</td>
<td>25.0</td>
</tr>
<tr>
<td>6</td>
<td>150</td>
<td>2,150</td>
<td>4.8</td>
<td>13</td>
<td>29.0</td>
</tr>
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<td>33.5</td>
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<tr>
<td>8</td>
<td>200</td>
<td>2,750</td>
<td>5.6</td>
<td>16</td>
<td>38.0</td>
</tr>
</tbody>
</table>

*Comparable stages and calculated VO₂ values of the cardiopulmonary exercise protocols of the bicycle (left; VO₂ according to the nomogram of Astrand and Ryhming31) and the treadmill (right; VO₂ predicted according to the formula of Givoni and Goldman30).
breathes through a mouthpiece attached to a nonrebreathing valve. Air is drawn from the valve at a constant rate of 175 mL/min and delivered to the O₂ and CO₂ analyzers. The method uses a distributive processing technique involving a waveform analyzer and a host computer. Expiratory flow, O₂, and CO₂ are measured using rapid-responding discrete analyzers: a pneumotachometer and variable-reluctance pressure transducer for flow, a permanent zirconia-based electromechanical cell for O₂, and a dual-beam infrared absorption chamber for CO₂.

These instruments were calibrated before every test using a standard 3-L syringe and precision reference gases taking humidity, ambient temperature, and barometric pressure into consideration. The waveform analyzer performed cross-product analysis on phase-aligned signals from the respective analyzers and continuous integration. The host computer provided additional computations and graphic presentations of VO₂, carbon dioxide output (VCO₂), ventilation, HR, and other relevant gas exchange parameters.

**Parameters**

- **HR** (in beats/min), VO₂ (mL O₂/min),¹ VO₂/kg body weight/min (functional capacity, which can be used to assess functional cardiopulmonary class),¹,²,³ VCO₂ (mL CO₂/min), and minute ventilation (Ve) (L of air/min) were measured, and the ventilatory equivalent for oxygen (Ve/VO₂)¹ as well as oxygen pulse, ie, VO₂/HR, which is equal to the product of stroke volume and the arterial-mixed venous O₂ difference,¹ respectively, were calculated. Maximal VO₂ (ie, VO₂ max, in mL O₂/min, at plateau) was defined as increase in VO₂<150 mL/min despite a ≥2.5% work increment for at least half a minute after beginning a new protocol stage.¹,²,³ Anaerobic threshold was defined as the point of coincidence of the following: (1) a minimum of the (Ve/VO₂); (2) the point after which both Ve and VCO₂ increased nonlinearly relative to VO₂; and (3) the point after which the respiratory quotient, ie, VCO₂/VO₂, began to consistently exceed its resting value.

**Statistical Analysis**

Since measured values at the end of the individual workload stages were not normally distributed, but instead accumulated nonspecifically, statistical analysis was not based on mean values and SDs. Rather, averages of data measured at the respective stages were expressed as medians. For statistical comparisons and for demonstration of linearity, measured values of each individual subject were transformed into a simple linear function assuming measured values at the end of each stage to be the functional values. The corresponding correlation coefficient (r) was used to measure the percentage of variance. The slopes of the medians and measured values at highest workloads were subjected to statistical analyses by means of Wilcoxon’s signed-rank test for unpaired samples; p values <0.05 were considered statistically significant.

**Results**

During bicycle testing, 10 of 21 subjects achieved the maximum workload, ie, 200 W, whereas the remainder terminated earlier due to leg muscle fatigue. There was a mean exercise duration of 14.3 min, corresponding to 180 W. On the treadmill, 18 subjects completed the entire protocol. The respective values for mean exercise duration and calculated average workload amounted to 15.5 min and 197 W. This 9% difference in wattage was statistically significant (p<0.05).

**Heart Rate**

On the bicycle, there was a linear increase in HR by a mean of 11 beats from one stage to the next according to the equation HR (beats/min)=87.27+11.37 times stage number (Table 2 and Fig 1). On the treadmill, starting from a slightly higher median at rest, a comparable linear increase was present as reflected by the equation HR=90.60+11.60 times stage number. The age-predicted HR value, defined as 220-age,¹,³ was not achieved on either mode of exercise testing by any subject. Comparison of both testing modalities did not reveal any relevant difference, neither between peak values nor slopes.

**Oxygen Uptake**

Starting from a median value of 284 mL oxygen per minute at rest, bicycle exercise testing led to a linear increase in VO₂ according to the equation VO₂ (mL oxygen/min)=344.44+293.73 times stage number (Table 2). On the treadmill where, again, higher resting values were found, this parameter rose according to the equation VO₂=488.86+285.90 times stage number starting from 389 mL oxygen per minute at rest. None of the subjects achieved a plateau in VO₂, irrespective of the protocol. With respect to predicted maximal values,¹ 110% were achieved on the bicycle, and 118% were achieved on the treadmill. Comparison of both testing modalities did not show any differences between values or slopes. An excellent conformity between bicycle VO₂ values calculated from the nomogram of Åstrand and Ryhming⁴¹ (Table 1) and the measured values of the present study (Table 2) were found.

At anaerobic threshold, mean VO₂ amounted to 1,311 mL oxygen per minute during bicycle exercise testing and to 1,497 mL oxygen per minute on the treadmill. This 15% difference was statistically significant (p<0.05).

**VO₂ per Kilogram Body Weight**

In relation to the body weight, bicycle testing revealed a proportionate rise in VO₂ per kilogram (mL oxygen/kg/min) as reflected by the equation VO₂/kg=5.40+4.23 times stage number (Table 2 and Fig 2). There were, again, lower resting values when sitting on the bicycle than when standing on the treadmill. Exercising on the latter device also demonstrated linearity between this parameter and the protocol as described by the equation.
Table 2—Medians*

| Parameter          | Mode     | Rest | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | r     |
|--------------------|----------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| HR, beats/min      | Bicycle  | 88   | 100   | 109   | 121   | 134   | 145   | 159   | 167   | 173   | 0.991 |
|                    | Treadmill| 91   | 101   | 111   | 121   | 133   | 145   | 156   | 171   | 181   | 0.942 |
| 
| \( \dot{V}O_2 \), mL/min | Bicycle  | 254  | 709   | 956   | 1196  | 1522  | 1526  | 2093  | 2415  | 2735  | 0.989 |
| \( \dot{V}O_2 \), mL/min | Treadmill| 389  | 854   | 1133  | 1334  | 1665  | 1894  | 2093  | 2446  | 2699  | 0.993 |
| \( \dot{V}O_2/body weight, mL/min/kg \) | Bicycle  | 4.2  | 10.7  | 15.0  | 19.2  | 23.1  | 27.4  | 31.8  | 37.3  | 37.7  | 0.989 |
| \( \dot{V}CO_2 \), mL/min | Bicycle  | 221  | 580   | 837   | 1177  | 1469  | 1516  | 2147  | 2495  | 2912  | 0.996 |
| \( \dot{V}CO_2 \), mL/min | Treadmill| 307  | 669   | 965   | 1150  | 1462  | 1746  | 2047  | 2469  | 2956  | 0.987 |
| \( \dot{V}t\), L/min | Bicycle  | 8.9  | 20.9  | 25.8  | 33.3  | 40.4  | 47.6  | 56.8  | 66.4  | 74.8  | 0.971 |
| \( \dot{V}t\), L/min | Treadmill| 12.7 | 21.8  | 28.1  | 35.4  | 40.5  | 44.9  | 54.4  | 66.6  | 78.0  | 0.978 |
| \( \dot{V}t/\dot{V}O_2 \), mL/mL | Bicycle  | 33   | 27    | 25    | 27    | 26    | 27    | 27    | 28    | 28    | ni    |
| \( \dot{V}t/\dot{V}O_2 \), mL/mL | Treadmill| 33   | 27    | 25    | 27    | 27    | 27    | 27    | 28    | 28    | ni    |
| \( \dot{V}O_2/HR \), mL/b | Bicycle  | 3.4  | 6.8   | 8.7   | 10.0  | 11.1  | 12.4  | 13.7  | 14.4  | 16.4  | ni    |
| \( \dot{V}O_2/HR \), mL/b | Treadmill| 4.6  | 8.5   | 10.3  | 11.9  | 13.0  | 12.9  | 13.6  | 14.1  | 16.4  | ni    |

*Medians (10th/90th percentiles in brackets) of HR and ventilatory as well as gas exchange responses to exercise on both modes, respectively, and r=reflecting conformity of the measured values in proportion to the protocol stages after transformation into approximate equations. ni=not indicated; \( \dot{V}O_2/HR \)=oxygen pulse.
whereas the formula for $\dot{V}_{O_2}/kg=6.90+4.15$ times stage number. With respect to this parameter, no statistical differences were found between both testing modalities, neither for a given value nor for the slope. A comparison between those values calculated according to the formula of Givoni and Goldman$^{30}$ (Table 1) and those measured in the present study (Table 2) did not reveal any relevant difference with respect to slope ($r=0.999$). For a given stage, however, calculation yielded lower values than those actually measured, which was likely due to the fact that calculation was based on a body weight of 75 kg, whereas 69 kg was the average body weight of the subjects in the present study.

**Carbon Dioxide Output**

Despite increases in slopes as the anaerobic thresholds are exceeded, $\dot{V}_{CO_2}$ (mL CO$_2$/min) values still obey linearity on both exercise protocols, ie, $\dot{V}_{CO_2}=200.21+329.14$ times stage number during bicycle exercise testing and $\dot{V}_{CO_2}=280.33+311.75$ times stage number on the treadmill (Table 2). Although there was a higher $\dot{V}_{CO_2}$ at rest on the treadmill, comparison of both testing modalities did not reveal any relevant difference between the peak values or between the slopes.

**Minute Ventilation**

In analogy to $\dot{V}_{O_2}$, there was a linear increase in $\dot{V}E$ (L room air/min) on both protocols despite higher values for the slopes above the anaerobic threshold (Table 2). On the bicycle, $\dot{V}E$ increased according to the equation $\dot{V}E=9.43+7.93$ times stage number. Treadmill exercise testing yielded $\dot{V}E=11.41+7.63$ times stage number. Despite a higher value at rest on the treadmill, statistical comparison did not reveal any relevant difference with respect to both the slopes and maximum values.

**Respiratory Equivalent for Oxygen**

Because of the normal shape of its graph, neither demonstration of linearity nor statistical comparison of both testing modalities were feasible with this parameter (Table 2). The data from both protocols were best fitted to quadratic equations, both of which, however, had comparably low regression coefficients. Nevertheless, for determination of anaerobic thresholds, minimum values were identified and amounted to 25 in both protocols.

**Oxygen Pulse**

Due to the fact that maximum $\dot{V}_{O_2}$ is 5 to 15 times its value at rest and maximum HR is two to three times its resting value,$^1$ the quotient, ie, oxygen pulse, does not obey strict linearity, especially at the beginning of exercise and toward peak effort (Table 2 and Fig 3). Accordingly, a linear relation between the protocol stages and this parameter could not be demonstrated. Instead, the data were fitted to an exponential equation, yielding $3.85+6.26e^{-2}$ times stage number in the case of the bicycle protocol ($r=0.973$) and $4.73+4.1e^{-2}$ times stage number during treadmill exercise testing ($r=0.984$). However, pairwise comparison of the measured values at comparable stages revealed an acceptable correlation of both protocols over their entire ranges. With respect to predicted maximal values,$^1$ 121% was achieved on the bicycle, and 124% was achieved on the treadmill.
patients with severe COPD, no differences were found regarding peak exercise capacity, obviously due to pulmonary limitations prior to cardiac parameters such as HR and VO$_2$ reflecting cardiac output becoming rate limiting in this small patient group. This study is at odds with another two comparing both exercise modalities in a greater series of patients suffering from chronic heart failure.\textsuperscript{40,41} In both of them, better performance with respect to peak exercise capacity, maximum VO$_2$, and ventilation were observed on the treadmill. Consequently, the superiority of the treadmill regarding these parameters appears to be of note only in patients without relevant pulmonary limitations.

On comparison of the two protocols, HR as a simple cardiac parameter showed a nearly identical response, both with respect to the values measured at comparable workloads as well as the slopes. Potential influences such as age of the patient, stroke volume, body temperature, and familiarity with the mode of exercise testing\textsuperscript{12,15-17} had been minimized by use of healthy volunteers familiar with both modes of exercise testing such that parallel increases in cardiac output were assumed.\textsuperscript{12,16} In addition, HR becomes the dominant determinant as work increases, since stroke volume shows a difference of about 3\% during bicycle and treadmill ergometry\textsuperscript{42} which is already maximal at relatively low stages.\textsuperscript{1,4,12,14} Thus, cardiac output is identical at comparable workloads for the two protocols used in the present study.

As a cardiopulmonary parameter, VO$_2$ represents the most objective measure of cardiac output.\textsuperscript{1,2,12,14,21} There was close agreement of both VO$_2$ values at comparable workloads as well as slopes from one stage to the next between the nomogram\textsuperscript{31} and measured values during bicycle ergometry and between the calculated\textsuperscript{30} and the measured VO$_2$ on the treadmill. Similarly, the measured values were comparable throughout the entire ranges of both protocols. Thus, the response of both HR and VO$_2$ are nearly parallel\textsuperscript{12,27} reflecting similar cardiac output at corresponding stages and, consequently, comparability of the two protocols.

The healthy subjects in this study did not achieve maximal VO$_2$ (VO$_2$ max) revealing a cardiac output potentially higher than would be necessary to exercise up to 200 W. Since achievement of a plateau in VO$_2$ is reproducible,\textsuperscript{1,4,28} but depends on the protocol used, the increment between stages,\textsuperscript{1,2,23,27,28,35,37,43} the muscle mass involved,\textsuperscript{4} training status,\textsuperscript{37,44} and concomitant cardiac diseases,\textsuperscript{1,12,23,43} frequently this parameter is not achieved especially in patients (as opposed to healthy people) and, consequently, does not as-

**FIGURE 3.** Correlation of oxygen pulse (VO$_2$/beat) values during treadmill (abscissa) and bicycle (ordinate) ergometry. Abbreviations and symbols as in Figure 1.

**DISCUSSION**

Each of the two methods for exercise testing, treadmill and bicycle ergometry, has advantages and disadvantages that account for their differing usage in various countries.\textsuperscript{1,12,17,36} There are numerous treadmill protocols,\textsuperscript{23-28} but, because of the difficulty in quantifying work,\textsuperscript{1} none can be compared with the well-defined stages of bicycle ergometry. Accordingly, it was the aim of this study to evaluate a new treadmill protocol that had been designed before on theoretical grounds to correspond to a bicycle protocol with 25-W stages such that two different exercise modalities would lead to identical increases in cardiac output, as reflected by HR and VO$_2$.\textsuperscript{1,2,12,14,21} Albeit this new protocol had been drafted to be used primarily in limited persons, testing was done in young and healthy subjects who can be expected to pass through as many stages of both protocols as possible as a prerequisite for demonstration of comparability throughout their entire lengths.

Although both protocols use comparable increment sizes, on the average, subjects exercised 9\% longer on the treadmill, and a considerably larger number completed the treadmill protocol without cardiopulmonary limitation than on the bicycle. Hence, larger workloads and longer exercise durations are tolerated and higher values of peak HR and peak VO$_2$ are achieved on the treadmill.\textsuperscript{1,20,22,23,35-38} Apparently forming the basis of an enhanced sensitivity of the treadmill with respect to detection of ischemic heart disease.\textsuperscript{20,23,36} This, in turn, is due to the fact that during treadmill ergometry, a greater amount of muscle mass is working than on the bicycle and, consequently, quadriceps muscles alone do not become exhausted as rapidly on the treadmill as they do on the bicycle.\textsuperscript{38,39}

In one study of Mathur et al\textsuperscript{11} consisting of eight
sume the same importance as does VO₂ at comparable workload as, for example, anaerobic threshold.

At anaerobic threshold, reproducibility of which is viewed with controversy,⁴⁻¹⁴,²²⁻²⁷,³⁷,⁴⁵⁻⁴⁷ VO₂ was 15% higher during treadmill ergometry than on the bicycle. This observed difference lies within the same order of magnitude as it did in the studies of Buchfuhrer et al,²² Myers et al,²³ and Hambrecht et al,²⁶ again reflecting a generally higher VO₂ on the treadmill due to a larger muscle mass involved as opposed to bicycle ergometry.¹,3,¹⁷,²⁰,²²,²³,³⁵,³⁶,⁴²,⁴⁴

VO₂ per kilogram body weight enables a classification of cardiopulmonary fitness²⁵ and functional capacity which, in turn, determines peak cardiac output, maximal stroke volume, exercise duration, and VE.⁴ In analogy to VO₂, comparable values were found with both exercise modalities, albeit with some tendency for increase on the treadmill. An enhancement of functional capacity by 10% in the last stage is not accounted for alone by an overall higher VO₂ on the treadmill, but may also be due to the expression of the results as medians together with the fact that half the healthy subjects did not reach the final stage on the bicycle.

Apart from slightly higher values at rest and at the lower stages during treadmill ergometry similar to other reports,²³,²⁶ an identical VO₂ was found at comparable workloads of both protocols. A potential impact of nutritional components that can alter carbon dioxide production and VE by up to 30%¹ was precluded by exercising in the fasting state. Despite surpassing the anaerobic threshold using both protocols, there was only little deviation of slopes comparing the segments of both lines below and above the anaerobic threshold. This points to comparable increment sizes of both protocols since, otherwise, different slopes would have been expected.²²

In spite of higher values at rest and at lower workloads on the treadmill, there was no difference in VE between the two protocols, neither regarding comparable workloads nor the slopes, such that a similar extent of exercise-induced metabolic acidosis can be assumed. The small increase in slopes above the anaerobic threshold not only illustrates the comparable extent of increment size already mentioned, but also the relation of this parameter to carbon dioxide production.⁵,²²

Due to the typical pattern of the VE/VO₂ during exercise, a linear plot relative to the workloads was achieved and, consequently, regression between both protocols does not appear useful. Accordingly, there are no correlation coefficients indicated (Table 2). However, a clear nadir of this parameter can be discerned beyond the second stage of either protocol, indicating anaerobic threshold. It also verifies that the subjects were normal with respect to cardiopulmonary function by means of its absolute values.¹ The small increase beyond the nadir reflects a comparably small incremental size in both protocols for the healthy subjects, as does the modest deviation of slopes of both VCO₂ and VE already mentioned. This shallow increase in VE/VO₂ observed with both protocols appears advantageous for determination of anaerobic threshold.²²

Comparable increases in oxygen pulse, which again do not increase linearly relative to protocol stages, were found with both protocols, but those values obtained on the treadmill at rest and at the beginning of exercise were about 10% higher (Table 2), reflecting a higher stroke volume.⁴²

In summary, the new treadmill protocol can be performed with ease on the part of subjects and, presumably, patients as well since, alternately, either speed or grade is increased from one stage to the next, thus facilitating coordination. It covers the activities of normal daily life for cardiac patients,¹²,¹⁶ which comprise a range of 40 to 190 W, especially in the setting of heart failure⁶⁻¹⁰,¹¹,²¹,³⁷ and advanced age¹⁴ such that this protocol appears best suited for evaluation of therapeutic effects such as, eg, the mode of pacing or medical treatment.⁵⁻⁷,⁴⁰

In terms of VO₂, other programs such as the Bruce and Elledal protocols begin at 15 mL O₂/kg/min, where severely disabled patients often face their upper limits⁹,¹⁰ and achieve more than 20 mL O₂/kg/min already at their second stage,²⁵⁻²⁷,³⁹ which, according to the classification of Weber et al,³⁴ requires almost an absence of heart failure. By contrast, the new protocol offers a means of assessing the entire range of activities of disabled cardiac patients also comprising low stages but, nevertheless, with an acceptable total duration, which should be around 10 min.¹,²²,²³ Furthermore, in comparison to

![Figure 4. Comparison of four different treadmill exercise protocols](image-url)
other treadmill protocols24-27 (Fig 4), a smaller increment in cardiac output over the total protocol length due to a relatively small incremental size frequently prevents the achievement of maximal VO2.1,22,25,27,28,35,37 Nevertheless, most of the healthy subjects were able to complete the entire protocol, and a relatively modest increase in VO2 facilitates anaerobic threshold identification.22 Both the linearity of the slopes of HR and cardiopulmonary parameters, as well as the values corresponding to its individual stages, meet those of a well-defined bicycle protocol with 25-W steps such that both protocols can be considered to be identical. Consequently, transformations of treadmill stages into watts with identical HRs and VO2 reflecting cardiac output as well as comparisons with other exercise modalities are feasible on the basis of body weight.

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