The Work Rate Divided to Heart Rate Ratio during an Incremental Exercise Test is an Effective Method for Estimation of Anaerobic Threshold

**Objective:** The effectiveness of work rate divided to heart rate ratio on anaerobic threshold (AT) estimation was evaluated.

**Material and Method:** Twenty five male subjects performed an incremental exercise test (15 W/min) until the limit of tolerance. During exercise, respiratory and gas exchange parameters were evaluated breath-by-breath. The heart rate was recorded as beat-by-beat. AT estimated from the work rate divided to heart rate ratio, heart rate versus work rate plot (Conconi method) and compared with the V-slope method.

**Results:** A deviation from linearity in heart rate was observed only in 6 subjects. Other 19 subjects have linear increase in heart rate to work rate relationships. The work rate divided to heart rate ratio showed a clear break point in all subjects and closely associated with the V-slope break point: 1.91±0.04 L/min vs 1.89±0.03 L/min. Absent of a break point in heart rate work rate relationship (76%) and an extremely low percent of association in AT estimation between Conconi and V-slope method (%16) may reduce reliability of Conconi test.

**Conclusion:** Thus, caution should be taken by investigators especially making important decision for patients and sports training. However, work rate to heart rate ratio could provide easy and reliable AT estimation.

**Key Words:** Anaerobic threshold, heart rate, conconi method, exercise, V-slope

**Introduction**
Cardiopulmonary fitness is a crucially important indicator of the body’s organs and system functions. Anaerobic threshold (AT) reflects the transition point from aerobic to anaerobic metabolism during muscular exercise performance. It has been widely used criteria for assessing cardiopulmonary fitness (1). In recent years, the popularity of AT concept has been increased and used for different purposes, including establishing an optimum training work rate (2), determining aerobic fitness (3), assessing the efficacy of treatment (4), improving cognitive functions (5), and even a patient’s suitability for major surgery (6).

In the last few decades, several invasive and non-invasive methods have been introduced to determine or estimate the AT. The most accurate and reliable method to determine AT is the direct testing of arterial blood lactate accumulation during incremental exercise test (7). However, this is not often applicable to most performers. The various non-invasive methods mainly based on metabolic and ventilatory gas exchange parameters, have been developed to estimate AT (1, 8, 9).

The V-slope method during incremental exercise has been shown as the most effective way to estimate AT non-invasively (8, 10, 11). This method based on...
detecting increased CO$_2$ output (VCO$_2$) as a function of O$_2$ uptake (VO$_2$) where extra CO$_2$ comes from lactate-bicarbonate buffer system during anaerobic metabolism (1, 8).

The techniques that based on respiratory and pulmonary gas exchange dynamics can be easily used in laboratory conditions, but may not be possible to apply some sports in the field. To solve this problem, heart rate-work rate relationships during exercise have been introduced as a non-invasive AT estimation outside the laboratory conditions (12).

It has been proposed that AT can be validly estimated simply by establishing the point at which heart rate linearity changes during exercise (12). However, there is no general agreement among the reports concerning the heart rate work rate-work rate deflection point (HRDP) and its relation with the actual AT (13-19). The vital disappointment in this technique is the observation of a linear increase in heart rate-work rate relationships during exercise performance in most subjects (13, 20, 21).

Due to wide application of AT in clinical and sports medicine for important decision, the methods used to estimate AT are of great importance. In this study, validity of AT estimation comparatively examined by using the HRDP and V-slope method. In addition, during an incremental exercise test, efficiency of the work rate divided to heart rate ratio on AT estimation was also examined.

Materials and Methods

Participants: Twenty-five male subjects (mean±SE, age: 20.2±0.3 yr; height: 180.8±1 cm; weight: 69.6±1 kg) were enrolled into this study after giving a written informed content. The University Ethics Committee approved the study protocol.

Before the test, the subject’s height and body mass were measured (Tanita, TBF 300 M, Japan). The exercise tests were performed in a climatically controlled laboratory where temperature was kept at around 22°C. The subjects familiarized with the laboratory environment and the experimental protocol that they would undergo. On the day of the test, they were instructed that taking no alcohol and stimulant drinks including coffee and tea, and had done no extenuating physical activity. All testing was performed between 08:00 and 10:00 AM.

General Procedures: All subjects performed an incremental exercise in the upright position on an electromagnetically braked ergometer (VIA sprint TM150/200P) that was completely adjustable to the physical dimensions of the subject. After a 4-min warm-up at 20 W, each subject performed a 1-min stage incremental exercise test to exhaustion with 15-W work increment (22). Then, the work load decreased to 20 W for 4 min as a recovery period. The pedalling frequency was between 50 and 70 rpm (average 60 rpm). Seat and handlebar heights were set for each subject.

During incremental exercise test, pulmonary gas exchange parameters were estimated breath-by-breath. Ventilatory parameters evaluated using a light weight low resistance turbine volume transducer (Triple V-Volume Sensor) and gas exchange parameters evaluated using a gas analyser system (MasterScreen CPX). The system was calibrated be for each test for temperature, barometric pressure, O$_2$ and CO$_2$ concentrations according to the manufacturer’s specifications. Cardiac parameters (including heart rate, ST, T, QT) were followed continuously using 12 lead ECG. The heart rate was recorded as beat-by-beat throughout the study.

Estimation of AT: V-slope (8) other conventional methods, i.e. increase in end tidal PO$_2$ without decrease end tidal PCO$_2$; and increase in ventilatory equivalent for O$_2$ without increase in ventilatory equivalent for CO$_2$ (9), used in AT estimation.

The break point in heart rate versus work rate plot was used to estimate AT (12). In addition, the work rate divided to heart rate ratio was also used to estimate AT (Figure 1).

Figure 1. Representative plots of V-slope method (upper graphs), work rate to heart rate ratio (middle graph) and linear increase of heart rate to work rate relationships (lower graph) during incremental exercise
**Statistical Analysis:** Values were expressed as mean and standard error (±SE). A paired t-test was used to evaluate values observed from the V-slope method and the heart rate versus work rate plot. During exercise, estimated AT values obtained both the work rate divided to heart rate ratio and the V-slope relationship were evaluated using linear regression analysis. Significance was set at P<0.05 for all statistical analyses.

**Results**

Maximal exercise capacity (W_max), maximal VO_2 (VO_2max) and VO_2 for per kg body weight were found to be: 223±5 W, 2.97±0.06 L/min, and 43.2±1.2 mL/kg, respectively. The VO_2 at the AT was found to be 1.91±0.04 L/min.

During incremental exercise test, the heart rate–work rate relationship were observed in three different ways: linear increases in 19 subjects (76%), left side deflection in 4 subjects (16%) and right side deflection in 2 subjects (8%) (Table 1).

**Table 1.** Maximal exercise capacity (W_max), work rate at the anaerobic threshold estimated from V-slope method and heart rate vs work rate relationship.

<table>
<thead>
<tr>
<th>Subjects No</th>
<th>W_AT (V-Slope) (W)</th>
<th>W_AT HR vs WR (W)</th>
<th>Wmax (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>155</td>
<td>Lineer</td>
<td>205</td>
</tr>
<tr>
<td>2</td>
<td>180</td>
<td>Lineer</td>
<td>230</td>
</tr>
<tr>
<td>3</td>
<td>155</td>
<td>Lineer</td>
<td>205</td>
</tr>
<tr>
<td>4</td>
<td>210</td>
<td>Lineer</td>
<td>265</td>
</tr>
<tr>
<td>5</td>
<td>150</td>
<td>Lineer</td>
<td>200</td>
</tr>
<tr>
<td>6</td>
<td>155</td>
<td>Lineer</td>
<td>210</td>
</tr>
<tr>
<td>7</td>
<td>170</td>
<td>Lineer</td>
<td>245</td>
</tr>
<tr>
<td>8</td>
<td>135</td>
<td>Lineer</td>
<td>195</td>
</tr>
<tr>
<td>9</td>
<td>150</td>
<td>Lineer</td>
<td>230</td>
</tr>
<tr>
<td>10</td>
<td>130</td>
<td>Lineer</td>
<td>215</td>
</tr>
<tr>
<td>11</td>
<td>170*</td>
<td>170W (LBP)</td>
<td>255</td>
</tr>
<tr>
<td>12</td>
<td>155*</td>
<td>155W (LBP)</td>
<td>260</td>
</tr>
<tr>
<td>13</td>
<td>140</td>
<td>Lineer</td>
<td>225</td>
</tr>
<tr>
<td>14</td>
<td>150*</td>
<td>150W (LBP)</td>
<td>260</td>
</tr>
<tr>
<td>15</td>
<td>130</td>
<td>165W (RB)</td>
<td>205</td>
</tr>
<tr>
<td>16</td>
<td>145</td>
<td>Lineer</td>
<td>235</td>
</tr>
<tr>
<td>17</td>
<td>125</td>
<td>Lineer</td>
<td>185</td>
</tr>
<tr>
<td>18</td>
<td>150</td>
<td>220W (RB)</td>
<td>245</td>
</tr>
<tr>
<td>19</td>
<td>125</td>
<td>Lineer</td>
<td>195</td>
</tr>
<tr>
<td>20</td>
<td>155</td>
<td>Lineer</td>
<td>230</td>
</tr>
<tr>
<td>21</td>
<td>120</td>
<td>Lineer</td>
<td>205</td>
</tr>
<tr>
<td>22</td>
<td>130</td>
<td>Lineer</td>
<td>225</td>
</tr>
<tr>
<td>23</td>
<td>160</td>
<td>Lineer</td>
<td>260</td>
</tr>
<tr>
<td>24</td>
<td>120*</td>
<td>120W (LBP)</td>
<td>225</td>
</tr>
<tr>
<td>25</td>
<td>95</td>
<td>Lineer</td>
<td>175</td>
</tr>
</tbody>
</table>

LBP: Left break point; RBP: Right break point.
* AT was similar in both test

Interestingly, the left deflection point in heart rate–work rate relationship associated with the AT estimated from the V-slope break point. However, the right side deflection point, did not associated with the AT estimated from the V-slope break point (Table 1). In these 2 subjects, the HRDP occurred above the AT (Table 1).

However, while the heart rate–work rate relationships occurred in linear manner, the work rate to heart rate ratio response to incremental exercise test showed a clear break point in all subjects (Figures 1) (Table). The break point obtained from the work rate to heart rate ratio was closely associated with the break point obtained in V-slope method (R=0.889, P<0.0001) (Figure 2).

**Figure 2.** Linear regression analysis of AT estimated from using VO_2 at the WR/HR break point and VO_2 at the V-slope point (n: 25).

**Discussion**

In this study, we have attempted to clarify two important issues: evaluating the effectiveness of HRDP on valid AT estimation, and then examining the validity of work rate divided to heart rate ratio on AT estimation. Due to the easy and inexpensive non-invasive application, Conconi test becomes popular especially in training (12). Importantly, this method has been modified for several sports (18, 24-28). However, there are some serious questions regarding its accuracy (20, 21). In the literature, it has been reported that the Conconi method is not suitable to determine efficient exercise protocols in patients with cystic fibrosis and importantly training programs associated with Conconi method might even be harmful in these patients (29).

In consistent with results of several previous studies, we have observed linear increases heart rate in response to the incremental exercise test in extremely high number of subjects (19 out of 25 subjects, 76%) (20, 21, 29, 30). Naturally, it is not possible to estimate AT under the condition of linear increase in heart rate. An observation of high percentage (86%) break point in heart rate to work rate relationship was reported in young healthy male subjects (17).
The physiological mechanisms behind the 3 different heart rate response, (i.e. linear increase, left side deflection and right side deflection) during incremental exercise test have still not been fully explained. It seems logical to believe that the break point in heart rate work rate relation is related with the myocardial function of heart rather than the change in metabolism from aerobic to anaerobic. The observation of absent of break point and also dissociation of AT and HRDP in most subjects excludes the direct and strong relationship between anaerobic metabolic end productions and heart rate deflection. It has been proposed that deflection in heart rate during muscular exercise is caused by activation of the anaerobic lactic acid mechanisms of ATP production (31). There are various suggestions concerning the occurrence of HRDP, including increased potassium and catecholamine levels and their effects on myocardial functions (32,33), neural systems and sympathetic–para sympathetic systems activities and change in beta-1 adrenoceptors (33, 34). A different behaviour of left ventricular ejection fraction was suggested as a possible reason for the different behaviour of HRDP (35). It is also suggested that the deflection in heart rate may occur predominantly in subjects with thicker heart walls and does not seem to bear any relation to heart volume (36).

In this study, HRDP occurred in only 6 subjects (24%). However, it should be emphasized that correlation between HRDP and AT estimated with V-slope method occurred in only four subjects (16%) (Table). However, in 2 of the subjects, HRDP was not associated with the AT, and it occurred markedly above the AT. This overestimation of AT using HRDP was in consistent with some previously reported studies (27, 29). A deflection point in heart rate work rate relationship does not often occur, and, when it does, it does not coincide with AT, either in pre-training or post-training conditions (37). Despite the marked decrease in maximal exercise capacity and anaerobic threshold, the heart rate and work rate relationships did not affected during incremental exercise with breathing low level of O2 (21).

It is suggested that exercise test protocol may have an important role on heart rate work rate deflection point during exercise (32, 38). During incremental exercise tests with various work rate increments have been shown no significant effects on heart rate work rate relationships (39).

In this study, while the heart rate increased linearly with increasing work rate, there was a clear break point at the transition from aerobic to anaerobic metabolism in work rate divided to heart rate ratio (Figure 1). The estimated AT from the V-slope break point significantly correlated to a deflection point in work rate divided to heart rate ratio during an incremental exercise test (Figure 2). It is well known that the V-slope method has been shown as the gold standard non-invasive method used to estimate AT. This method based only detecting the metabolic changes (18).

In conclusion, absent of break point in heart rate work rate relation and extremely low percent of association in AT estimation between HRDP and pulmonary gas exchange indices may reduce reliability of the Conconi test. Therefore, caution should be taken by investigators especially making important decision for patients and sports training. However, work rate to heart rate ratio could provide easy and reliable AT estimation, and importantly it may be incorporated to set exercise intensity parameters for patient’s rehabilitation in clinical medicine.

Funding:
No funding.

Conflicts of interest:
There is no conflicts of interest.

Acknowledgements
Each author has participated sufficiently, intellectually or practically, in the work to take public responsibility for the content of the article, including the conception, design, and conduct of the experiment and for data interpretation.

References