Anaerobic Threshold Approximation with Minimum Number of Blood Samples

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***Abstract* — In this paper the anaerobic threshold measuring and approximation with minimum number of blood samples is described. Anaerobic thresholds are calculated for athletes tested on a bicycle ergometer and treadmill ergometer where the heart rate and pulmonary ventilation parameters, oxygen consumption and carbon dioxide expenditure are continuously measured. The main goal of the paper is the possibility of minimizing the number of blood sampling for lactate measurements from which the lactate curve and anaerobic threshold can be estimated.**

Keywords* — *anaerobic threshold, bicycle egometer, curve fitting, invasive lactate measuring, lactate curve, lactate estimation, treadmill

I. Introduction

The lactate threshold (LT) is the maximal effort or workload intensity that an athlete can maintain for an extended period of time with little or no increase in lactate in the blood [1, 2, 3]. At the anaerobic threshold (AnT) the exercise is at an intensity beyond which blood lactate concentration is linearly related to exercise intensity. The tests show that in endurance sports, AnT may be a better indicator of aerobic endurance than VO_2max (maximal oxygen uptake), because AnT can change without changes in VO_2max. VO_2max appears to be a less sensitive indicator of changes in training status than either the lactate threshold or the ventilatory anaerobic threshold. It is an effort or intensity and not a specific lactate level. It is most often described as speed in km/h (for treadmill examination), or as power in watts (for bicycle ergometer [4, 5, 6]. During the examination also heart rate (HR) and pulmonary ventilation parameters (VE), oxygen consumption (VO2) and carbon dioxide expenditure (VCO2) are continuously measured. The lactate curve is determined from several blood samples collected during the stress test with gradually increased physical workload. On the one hand, there should be as many blood samples as possible, for the most accurate determination of the lactate curve. On the other hand, there should be as few blood samples as possible, because this is an invasive procedure. In common practice, 3 to 5 blood samples are used during the examination. In the case of 3 samples, they are collected at the beginning of the stress test at low workload intensity, then at the moderate workload intensity and finally in the third minute after an exhausting maximum load.

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Fig. 1. Principle of invasive lactate measurement based on blood sample

The principle of invasive lactate measurement is shown in Fig. 1. Blood sample is taken from finger and after lactate value is measured by measuring unit [7]. The lactate measuring during the examination on tradmill or bicycle ergometer is shown in Fig. 2 or Fig. 3 respectively. Because in the case of a treadmill test, the subject runs, it is necessary to stop the run for take the blood sampling, on the contrary, the examination on a bicycle ergometer does not have to stop.

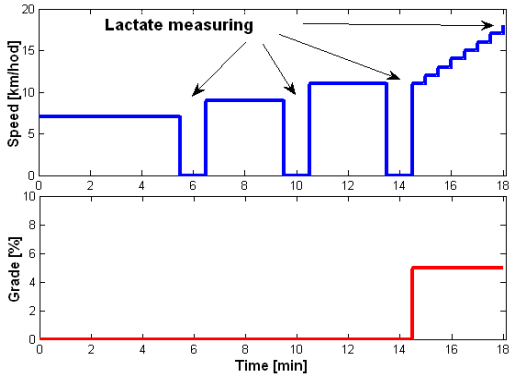

Fig. 2. Example of lactate measuring during examination on treadmill ergometer

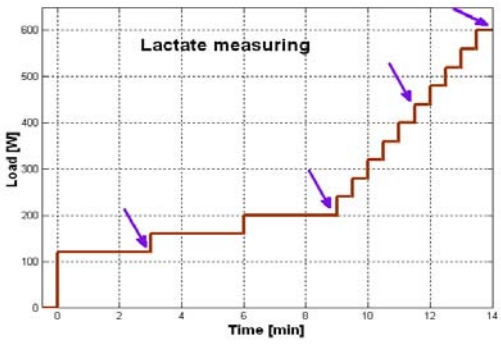

Fig. 3. Example of lactate measuring during examination on bicycle ergometer

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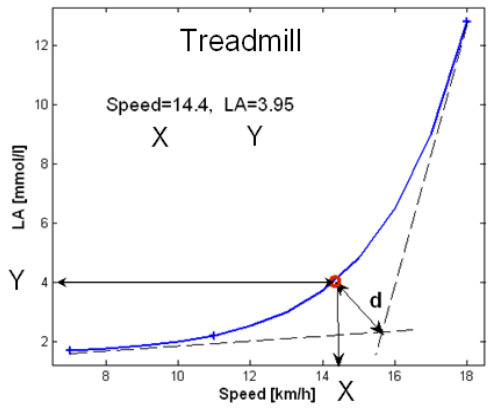

Fig. 4. Example of lactate curve and AnT (14.6 km/h) found after examination on treadmill ergometer. The curve is determined by 3 measured values of speed and lactate

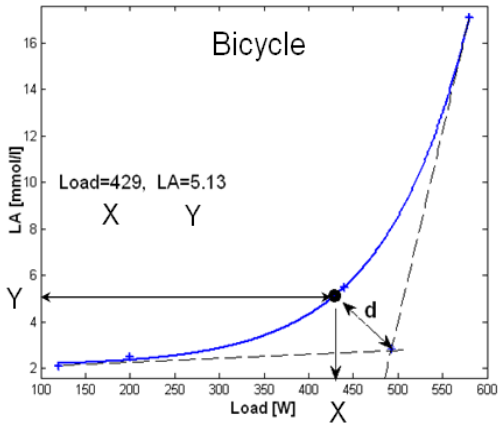

Fig. 5. Example of lactate curve and AnT (429 W) found after examination on bicycle ergometer. The curve is determined by 4 measured values of load and lactate

II. Methods

Mostly first-class endurance athletes were tested by the invasive method (usually 3 to 4 blood samples). Cardiopulmonary exercise testing (CPET) [8], also referred to as a VO_{2max} (maximal oxygen consumption) test is a specialized type of stress test used to determine the cardiorespiratory capacity of the subject. The data about circulatory and respiratory functions were collected to understand classification of functional capacities in relation to average values of healthy averaged populations of various ages. CEPT data were stored. Fig. 4 (treadmill) and Fig. 5 (bicycle) are an example of determining AnT from measured lactate values [9 - 13]. Curve fitting was performed by exponential regression by

$$y = c_1 + c_2 \cdot e^{c_3 \cdot x} \tag{1}$$

The c_1, c_2, c_3 coefficients were calculated by the Matlab optimization program. Then, the equations tangent to the curve at the beginning and end of the curve were calculated and the lines intersection was found. The optimization then search the minimum distance (d in Fig, 4 and 5) of the intersection point from the curve

$$d = \left\{ \sqrt{\left(x - p_x\right)^2 + sc\left[\left(c_1 + c_2 \cdot e^{c_3 \cdot x}\right) - p_y\right]^2} \right\}_{min} \tag{2}$$

where p_x, p_y are points of intersection and sc is the "scale"

$$sc = \left(\frac{max(x) - min(x)}{max(y) - min(y)} \right)^2 \tag{3}$$

Fig. 4 and 5 show examples of experiments where the curve from all measured values are shown The curve in Fig. 4 was derived from the following measured values: *Speed* [km/h]=[7 11 18]; *Lactate* [mmol/l]=[1.7 2.2 12.8]

The curve in Fig. 5 was derived from the following measured values: *Load* [W]=[120 200 440 580]; *Lactate* [mmol/l]=[2.1 2.5 5.5 17.1].

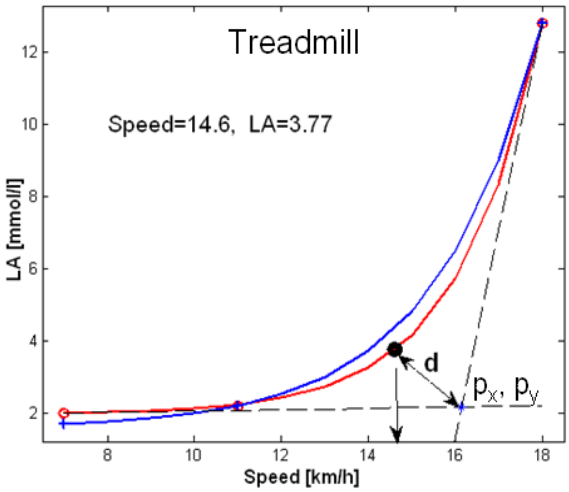

Fig. 6. Example of lactate curves for different initial values on treadmill ergometer. The correct AnT values are [Load = 14.6 km/h, LA= 3.77 mmol/l]. Measured - blue curve, Approximation from 3 lactate measurements - Red curve

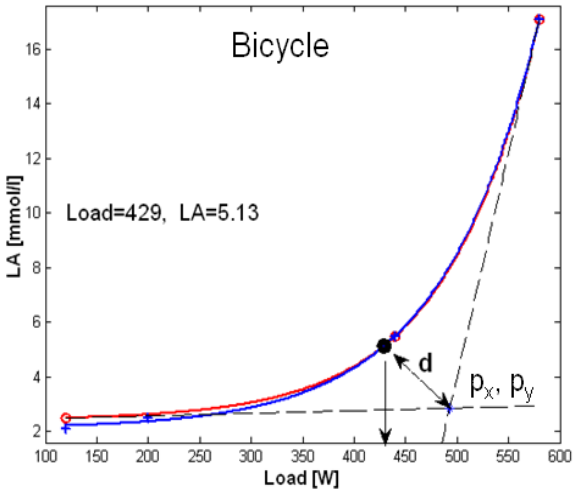

Fig. 7. Example of lactate curves for different initial values on bicycle ergometer. The correct AnT values are [Load = 429 W, LA= 5,13 mmol/l]. Measured - Blue curve. Approximation from 3 lactate measurements - Red curve

Fig. 6 and 7 show the results of the lactate curves (red curves), which were derived from 2 measured values of lactate and one (first value) value, which was obtained by estimation. Blue curves obtained by measurement are also shown for comparison. Blue curves were obtained by measuring from 3 points (Fig. 6) and by measuring from 4 points (Fig. 7). It can be seen from the previous examples

that in that curves in Fig. 7 are almost identical, while in the first case }Fig. 6) they are slightly different. This is because in the second case the measuring point was chosen for a relatively larger load value, Load = 400 [W], with a maximum Load = 600 [W], while in the first case the speed was only 11 km/h and the maximum speed was 18 km/h. Therefore, in the case of measuring lactate from only 2 points, the first measured point must be taken under sufficient load.

III. Results

The results are presented in the following 2 examples, again the first example for a treadmill ergometer and the second for a bicycle ergometer. . The measured values are in the first 2 lines of Tab. 1 and Tab. 2 respectively. In Tab. 1 are 3 measured LA values; in Tab. 2 are 4 measured LA values. The second 2 rows (rows 3 and 4) in Tab. 1 and Tab. 2 contain only 2 measured values (from the previous 2 lines) and one estimated value (displayed in red). In Tab. 1 are values for top league football player (aged 24 years), and in Tab. 2 are values for cyclist (aged 14 years). The results are shown in Tab. 1 and 2 as columns with blue values.

After processing a series of measurements, it appears that the estimated lactate value is calculated as the lactate value of the first measuring point multiplied by the constant k_{tre} = 0.85 (Standard deviation = 0.06, for treadmill ergometer) or k_{bic}= 0.67 (Standard deviation = 0.11, for bicycle ergometer). It is, of course, necessary to follow our way of increasing the load on the ergometers and take the second value of lactate at maximum load. In Tab. 1 and Tab. 2 the Lam are measured values and LAe value is estimated.(red).

Example 1 - for a treadminll ergometer (see values in Tab, 1). The first point is calculated by estimation:

$$LA(1)_{EST} = k_{tre} \cdot LA(2) = 0.85 \cdot 2.8 = 2.38 \quad (4)$$

After adding the load vector and lactate vector, the values from which the lactate curve is calculated are as follows:

Speed=[7 11 20]; *LAe*=[2.38 2.8 13.2];

Result is shown in Fig. 8. Estimated values are [15.3 4.55], values from 3 measured points are [15.5 4.49]

Example 2 - for a bicycle ergometer (see values in Tab. 2) The first point is calculated by estimation:

$$LA(1)_{EST} = k_{bic} \cdot LA(2) = 0.67 \cdot 7.7 = 5.16 \quad (5)$$

After adding the load vector and lactate vector, the values from which the lactate curve is calculated are as follows:

Load=[70 130 175]; *LAe*=[5.16 7.7 11.6];

Result is shown in Fig. 9. Estimated values are [124 7.33], values from 4 measured points are [116 6.93].

TABLE 1. MEASURD AND ESTIMATED VALUES FOR TREADMILL ERGOMETER. TOP LEAGUE FOOTBALL PLAYER

Speed	**7**	**11**	**20**	**15.5**	**km/h**
LAm	**2.5**	**2.8**	**13.2**	**4.49**	**mmol/l**
Speed	**7**	**11**	**20**	**15.3**	**km/h**
LAe	**2.38**	**2.8**	**13.2**	**4.55**	**mmol/l**

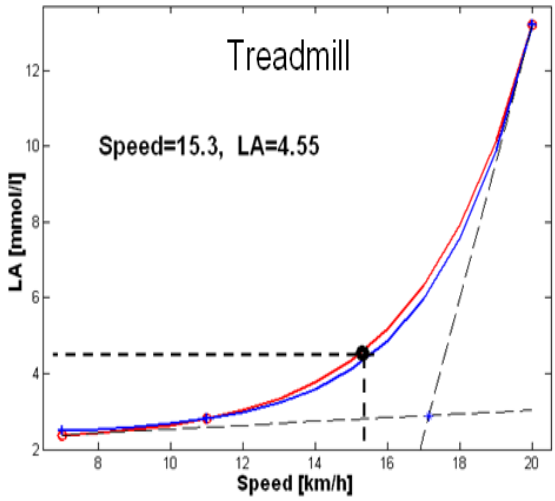

Fig. 8. Approximation from 2 LA measurements and 1 estimation value (red points, red curve).. Approximation from 3 LA measurements (blue points, blue curve). See Tab. 1 for values

TABLE 2. MEASURED AND ESTIMATED VALUES FOR BICYCLE ERGOMETER. CYCLIST AGED 14 YEARS

Load	**35**	**70**	**130**	**175**	**116**	**W**
LAm	**5.1**	**5.4**	**7.7**	**11.6**	**6.93**	**mmol/l**
Load		**70**	**130**	**175**	**124**	**W**
LAe		**5.16**	**7.7**	**11.6**	**7.33**	**mmol/l**

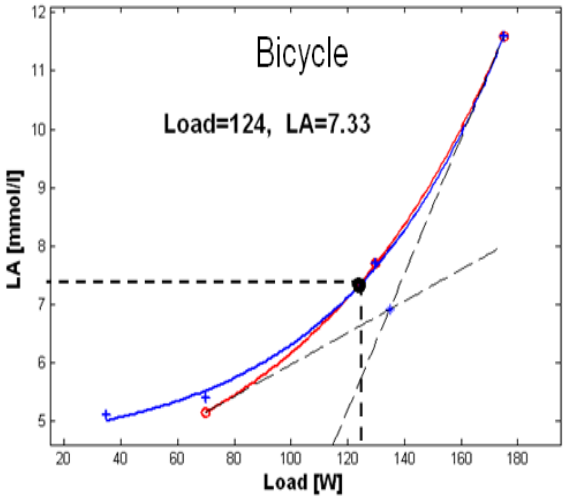

Fig. 9. Approximation from 2 LA measurements and 1 estimation value (red points, red curve).. Approximation from 4 LA measurements (blue points, blue curve). See Tab. 2 for values

The previous results presented in Fig. 8 and Fig.9 shown that in the case of suitably selected measurement points, the lactate curve can be determined relatively accurate from only 2 lactate measurements and one initial estimated value. Therefore, obtain results only from 2 blood samples..

IV. Conclusion

A new method of estimating the lactate curve and main parameters of anaerobic threshold (AnT) by the invasive method from the minimal number of blood samples taken during the examination on the treadmill and bicycle ergometer was described. The LT curve can be determined

from a total of 3 values, the first value (corresponding to the initial low intensity workload) being determined by estimation and the other two values (at medium intensity workload and after maximum intensity workload) being obtained by direct blood sampling. If we use this method, certain basic conditions must be met. During the first blood sampling, the intensity of the load must reach the moderate level, and during the second sampling, we try to obtain the LAmax value, i.e. the sampling is performed in the 3rd minute after the completion of the exhausting maximum load. The described method is especially suitable in sports practice but the applicability of this method in practice still requires its verification on a larger number of measurements. There are also non-invasive methods e.g. the V-slope method with good results [11, 12, 14, 15, 16].

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