Journal of Human Kinetics volume 12, 2004, 135-146

Reliability o Invasive ad Non-Invasive Anaerobic Threshold Estimation in Young Swimmers

by

Marek Strzala[1], Aleksander Tyka[2], Malgorzata Zychowska[2]

Authors attempted to confront two methods of anaerobic threshold (AT) estimation in swimmers: lactic invasive D_{max} (Cheng et al. *1992) and non-invasive ventilation V_{slope} method (Beaver* et al*. 1986) modified by authors. The research was conducted on two groups of swimmers (I - 16,4±0,7 years and II - 14±0,8 years) each consisting of 12 subjects. During the testing cycloergometer exercise, the workload was increased every 3 min. by 30 W. The experimental design allowed for the determination ATs simultaneously with two methods. In both groups the level of lactic threshold was higher than the Vslope (p=0.001). High correlation coefficients were estimated between lactic thresholds in blood (LA) and workload (WL) in both methods (r=0.84–0.91; p=0.001). Workload at the D_{max} threshold correlated stronger with $\dot{V}O_{2\,max}$ (r=0.80, p=0.001), than WL at V_{slope} threshold (r=0.67, p=0.001).*

Keywords: *swimmers, anaerobic threshold, invasive D_{max} method, non-invasive V_{slope}, $\dot{V}O_{2\,max}$*

[1] Department of Theory and Methodics of Watersports, Academy of Physical Education, Cracow
[2] Institute of Human Physiology

Introduction

The increase and maintenance of aerobic capacity is the basic target of training process in disciplines like cycling, distance running, Nordic skiing, swimming etc. Volume of physical workloads during training should be very precise in order to cause specific effects in functional abilities (Parker 1989; Costill *et al.* 1992; Issurin *et al.* 2001). The intensity of exercises which improve cardio-respiratory capacity of humans should range from 50 to 85% of $\dot{V}O_{2\,max}$ (American College of Sports Medicine 1990). This wide range of training loads is also used in methods determining the level of physical capacities in athletes, healthy and disabled subjects. One of the best methods of determining endurance abilities is the evaluation of anaerobic threshold (AT) with invasive or non-invasive methods (Wasserman *et al.* 1973; Beaver 1986; Kindermann *et al.* 1979; Stegmann 1981; Roecker *et al.* 2000; Gaskill *et al.* 2001).

The determination of AT in athletes is relatively difficult, because of methodological inconsistencies and application of different experimental procedures in laboratories around the world (Jacobs *et al.* 1981; Stegmann *et al.* 1982; Beaver *et al.* 1985, 1986; Gaesser 1986; Pyne 2001). The following notions are related to the anaerobic thresholds: maximal lactate state (MLSS) (Stegmann *et al.* 1982; Heck *et al.* 1985; Urhausen *et al.* 1993; Dobbins *et al.* 1998; Beneke 2003), speed adequate to lactate minimum (LMS) (Tegtbur *et al.* 1993), lactate threshold (LT) (Beaver *et al.* 1986; Wasserman *et al.* 1990; Roecker *et al.* 2000), OBLA threshold (Jacobs *et al.* 1981; Sjödin *et al.* 1981; Karlsson *et al.* 1982), individual anaerobic threshold (IAT) (Stegmann *et al.* 1981; McLellan *et al.* 1989), ventilation threshold (VT) (Wassermann *et al.* 1973; Beaver *et al.* 1985; 1986, Gaesser *et al.* 1986,) and threshold of metabolic decompensated acidosis (TDMA) (Reinhard *et al.* 1979).

The vast quantity of methods determining AT does not simplify the choice of the most universal one for sport practitioners, especially which could be used in optimization and individualization of athletes work loads. According to the above mentioned notions authors of this work attempted to confront two methods of anaerobic threshold (AT) estimation in swimmers: lactic invasive D_{max} (Cheng *et al.* 1992) and non-invasive ventilation V_{slope} (Beaver *et al.* 1986).

Material and methods

The research was conducted on 24 swimmers from Sport School from Oswiecim, divided into two groups, each consisting of 12 subjects. The first group included 16-18 years old swimmers (16.4±0.7 years) with 4th and 5th

degree of biological development (4.6±0.5°) according to the Tanner scale (1963) and with 8-10 years of training experience. The second group consisted of subjects aged 13-15 years (14±0.8 years) with 3rd-5th degree of biological development (3.4±0.8°) and 5-7 years of training experience. Specific anthropometric and functional characteristics of the tested subjects are presented in table 1.

Table 1

Specific anthropometric and functional characteristics of young swimmers

Variable	Group I		Group II	
	$\bar{x}$	SD	$\bar{x}$	SD
Body height [cm]	178.6	5.9	168.8	4.5
Body mass [kg]	67.2	6.5	57.17	6.6
Lean body mass [kg]	60.8	5.1	52.27	6.6
Absolute $\dot{V}O_{2\,max}$ [l·min-1]	3.72	0.34	3.33	0.32
Relative $\dot{V}O_{2\,max}$ [ml·kg·min-1]	55.26	5.52	57.91	5.89

During a progressive cycloergometer (900E Jaeger, Germany) exercise until volitional exhaustion authors determined the anaerobic threshold (AT) with the use of lactic and ventilation methods (Roecker *et al.* 2000). The test was preceded by a 3 min. warm-up with intensity of 45%$\dot{V}O_{2\,max}$, followed by 30 W increments every 3 min. The exercise lasted until the subject was unable to sustain 60 revolutions per minute with a specific workload. The measurements were conducted during 30 s intervals with 919 ER MEDIKRO (Finland) apparatus. The following ventilation variables were registered: minute oxygen uptake ($\dot{V}O_2$), minute carbon dioxide exhalation ($\dot{V}CO_2$), oxygen percentage in exhaled air (FeO_2), carbon dioxide percentage in exhaled air ($FeCO_2$), respiratory quotient (RQ), frequency (FR) and breath volume (T$\dot{V}$), minute ventilation ($\dot{V}_E$), ventilation equivalent for CO_2 ($\dot{V}_E \cdot \dot{V}CO_2^{-1}$) and O_2 ($\dot{V}_E \cdot \dot{V}O_2^{1}$).

During the last 30 s of each workload, blood samples from the fingertip were taken for lactate concentration evaluation with the use of miniphotometer (PLUS DR LANGE, Germany). On the basis of above mentioned physiological and biochemical variables dynamics of anaerobic thresholds were determined with the use of D_{max} and V_{slope} methods. The AT point in oxygen uptake (fig. 1) and workload (fig. 2) were determined in invasive D_{max} method on graphically presented lactate curves. The V_{slope} method (Beaver *et al.* 1986) modified by authors was used for determination of non-invasive anaerobic threshold. $\dot{V}O_2$ and $\dot{V}CO_2$ ventilation variables were analyzed in 30 s intervals, not „breathe by breathe” or in 20 s intervals as in case of Gaskill *et al.* (2001). Figure 3 shows typical changes in exhaled CO_2 as a function of oxygen uptake. According to the assumption of this method AT appears at this intensity, where $\dot{V}O_2$ and $\dot{V}CO_2$ lines intersects. In order to avoid subjectivism three randomly chosen experienced physiologists took part in calculations.

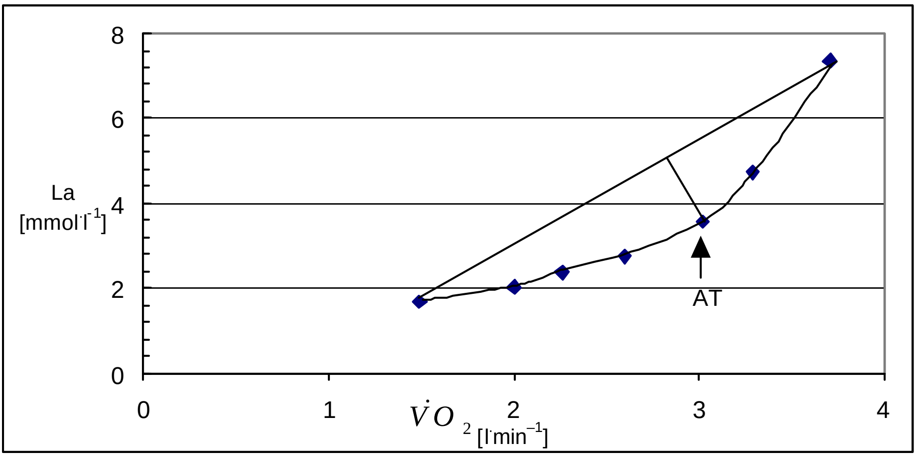

Fig. 1

Changes in blood lactate concentration as a function of $\dot{V}O_2$ *in subject G.M.*

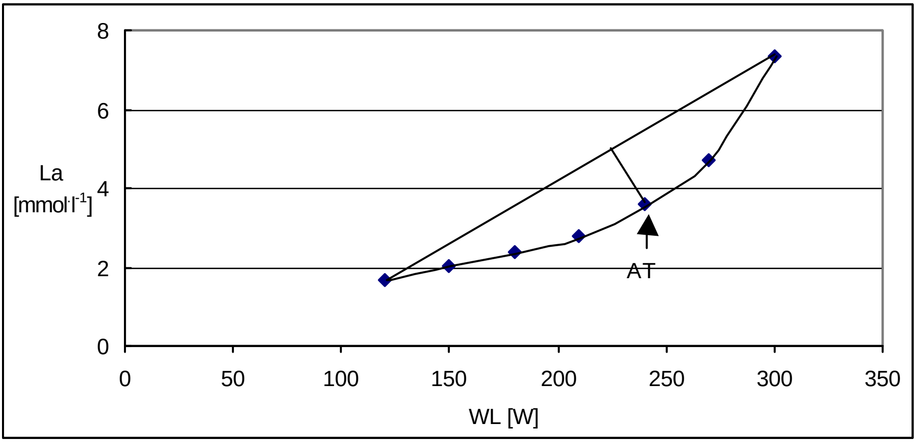

Fig. 2

Changes in blood lactate concentration as a function of workload (WL) in subject G.M.

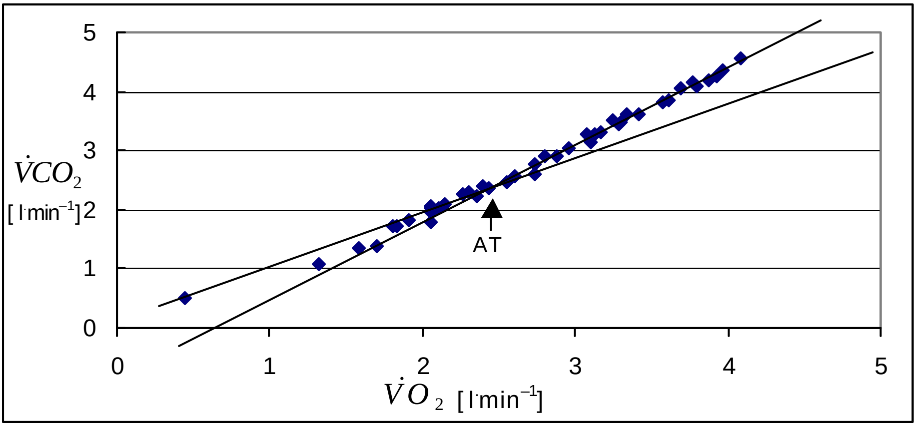

Fig. 3

Changes in $\dot{V}CO_2$ *as a function of* $\dot{V}O_2$ *in subject G. M.*

Statistical analyses were performed with the use of STATISTICA 6.0 (StatSoft, USA). Basic descriptive statistics were calculated. In order to determine significance of differences between established anaerobic thresholds ANOVA-MANOVA was performed. The relationship between the level of anaerobic thresholds and other variables was established with the use of partial correlation coefficients with controlling variables.

Results

The analysis of variance with repeated measures between three methods of AT determination and lactate concentration (La), workload (WL) and minute oxygen uptake ($\dot{V}O_2$) showed significant differences (p=0.001) in both groups of swimmers (table 2). ANOVA results showed, for both groups, that the level of AT determined with the D_{max} method (changes of lactate concentration as a function of $\dot{V}O_2$ and WL) were significantly different in comparison to the level of these coefficients at the ventilation threshold V_{slope} (p=0.001).

Table 2

Mean values and ANOVA results of lactate concentration (La), workload (WL) and oxygen uptake ($\dot{V}O_2$) AT the anaerobic threshold determined with lactic D_{max} method (La-$\dot{V}O_2$ and La-WL) and ventilation (V_{slope})

		Group I (n=12)						Group II (n=12)					
		La [mmol·l^{-1}]		WL [W]		$\dot{V}O_2$ [l·min^{-1}]		La [mmol·l^{-1}]		WL [W]		$\dot{V}O_2$ [l·min^{-1}]	
		$\bar{x} \pm SD$		$\bar{x} \pm SD$		$\bar{x} \pm SD$		$\bar{x} \pm SD$		$\bar{x} \pm SD$		$\bar{x} \pm SD$	
Dmax	**La-VO$_2$**	3,80 ±0,54	F=37,39, df = 2,22 , p< 0,001	207,5 ±29,8	F=58,14 , df = 2,22, p< 0,001	2,68 ±0,49	F=12,71, df = 2,22, p< 0,001	3,48 ±0,65	F=15,59, df = 2,22, p< 0,001	182,5 ±20,1	F=18,88, df = 2,22, p< 0,001	2,45 ±0,34	F=9,77, df = 2,22, p< 0,001
	La-WL	3,90 ±0,46		210 ±25,5		2,68 ±0,42		3,84 ±0,55		185 ±21,5		2,44 ±0,32	
Vslope	**VCO$_2$-VO$_2$**	3,14 ±0,45		182,5 ±23,7		2,43 ±0,32		2,64 ±0,26		160 ±14,8		2,18 ±0,18	

The threshold values V_{slope} (La, WL and $\dot{V}O_2$) were lower than those registered in the D_{max} method: La by 20-30%, WL by 13-14% and $\dot{V}O_2$ by 10% in both groups. The results of partial correlations with controlling the calendar age of all tested swimmers, allowed to determine the relationship between the level of AT determined with the D_{max} and V_{slope} methods and maximal minute oxygen uptake ($\dot{V}O_{2\,max}$). Results presented in table 3 showed that the strongest correlation was calculated between $\dot{V}O_{2\,max}$ with WL at lactate threshold (La-WL) (r=0.80, p=0.001). WL and $\dot{V}O_2$ threshold values in the V_{slope} method showed the smallest correlation with $\dot{V}O_{2\,max}$ (table 3).

Table 3

Partial correlations of $\dot{V}O_{2\,max}$ with WL and $\dot{V}O_2$ threshold values, determined with the D_{max} and V_{slope} methods with controlling calendar age of all swimmers (n=24)

	Dmax La-$\dot{V}O_2$	Dmax La-WL	Vslope
		WL	
$\dot{V}O_{2\,max}$ (l·min^{-1})	r=0.73, p<0.001	r=0.80, p<0.001	r=0.67, p<0.001
		VO2	
	r=0.68, p<0.001	r=0.72, p<0.001	r=0.59, p<0.002

In order to determine the validity and reliability of analyzed methods of AT determination in swimmers the analysis of partial correlation with controlling the calendar age was used. A strong correlation was determined between WL (r=0.89, p<0.001) and $\dot{V}O_2$ (r=0.91, p<0.001) threshold results D_{max} and V_{slope} methods (table 4).

Table 4

Partial correlations of AT levels determined with D_{max} and V_{slope} methods controlling calendar age of all swimmers as a function of WL and $\dot{V}O_2$ threshold values (n=24)

			WL			
Dmax La-$\dot{V}O_2$	r=0.84, p<0.001	DmaxLa-WL	r=0.89, p<0.001	Vslope	r=0.76, p<0.001	Dmax La-$\dot{V}O_2$
			VO2			
Dmax La-$\dot{V}O_2$	r=0.84, p<0.001	Dmax La-WL	r=0.91, p<0.001	Vslope	r=0.79, p<0.001	DmaxLa-$\dot{V}O_2$

Discussion

The problem of invasive and non-invasive anaerobic threshold determination in athletes during the last 20 years was the subject of many discussions and controversies (Stegmann 1981 1982; Karlsson 1982; Heck 1985; Beaver 1985; Hughson 1987; Gaskill 2001). The use of different testing protocols, different laboratory techniques, research tools and inconsistent interpretations of AT caused, that this research problem is still actual. Small percentage of research projects related to the validity and reliability of AT determination in sport may be only one of the examples. In this work the observations performed with swimmers were used as an attempt of usefulness of AT determination with two methods – invasive D_{max} (Cheng *et al.* 1992) and non-invasive V_{slope} (Beaver *et al.* 1986).

Anaerobic threshold, determined graphically with D_{max} method in case of changes of La in WL function appeared at La concentration level equal to 3,90±0,46 $mmol{\cdot}l^{-1}$ in group I and 3,84±0,55 $mmol{\cdot}l^{-1}$ in group II, while 3,80±0,54 $mmol{\cdot}l^{-1}$ and 3,48±0,65 $mmol{\cdot}l^{-1}$ in case of La-$\dot{V}O_2$ respectively. The mean La values were below the 4 $mmol{\cdot}l^{-1}$ „onset of blood lactate accumulation" (Karlsson and Jacobs 1982), which is very often used in swimmers in evaluation of endurance capabilities. Stegmann *et al.* (1981) determined the so called individual anaerobic threshold (IAT). In case of 18 year old swimmers the results of La thresholds determined with the IAT method (3,9±0,8 $mmol{\cdot}l^{-1}$) were similar as in the presented study (D_{max}), however the workload was increased by 50 W every 3 min. They also determined mean La thresholds values for soccer players (3,91±1,1 $mmol{\cdot}l^{-1}$), physical education students (4,6±1,2 $mmol{\cdot}l^{-1}$) and long-distance runners (2,1±0,5 $mmol{\cdot}l^{-1}$) which were characterized with similar values as rowers (1982).

In presented research V_{slope} ventilation threshold appeared earlier with the La method (3,14±0,45 $mmol{\cdot}l^{-1}$ in group I and 2,64±0,26 $mmol{\cdot}l^{-1}$ in group II), than in D_{max} method. Data presented by Loat and Rhodes (1996) also showed the existence of differences between ventilation and lactic thresholds. For example, lactic AT determined with IAT method in cyclists appeared at mean VO_2 equal to 3,33±0,58 $l{\cdot}min^{-1}$ La concentration 2,92±0,99 $mmol{\cdot}l^{-1}$, while ventilation threshold (Vslope) at 3,01±0,51 $l{\cdot}min^{-1}$ and 2,27±0,67 $mmol{\cdot}l^{-1}$. respectively.

Significantly lower V_{slope} thresholds values may be interpreted properly by Wasserman *et al.* (1990). According to them $\dot{V}CO_2$-$\dot{V}O_2$ curve steeper above the anaerobic threshold, mainly because of CO_2 increase in consequence of lactate buffering by HCO_3^- and additional CO_2 production in aerobic metabolism. The change in curve shape is identified by $\dot{V}O_2$ at which lactate starts to be buffered by HCO_3^- and is theoretical transition point from completely aerobic to aerobic-anaerobic work. According to Beaver *et al.* (1986) bicarbonate compounds are the main buffer of metabolic acids in human organism fluids, then increase in La concentration in blood causes obligatory the increase in carbon dioxide release, what may be registered in exhaled air.

It seems, that such an explanation of acquired curve describing changes during exercise with progressive intensity may explain the differences appearing in levels of threshold coefficients determined with the D_{max} and V_{slope} method.

On the basis of acquired results it may be stated, that both methods of AT threshold determination Vslope and Dmax (La concentration as a workload function) showed reliability, however different biochemical and physiological background of appearance (Wasserman *et al.* 1973, 1990; Karlsson *et al.* 1982; Beaver *et al.* 1986; Gaesser *et al.* 1986; Loat *et al.* 1996). Strong partial correlation appeared between workload (WL) at threshold (r = 0,89, p < 0,001), as well as oxygen uptake ($\dot{V}O_2$) (r = 0,91, p < 0,001). The correlations between threshold V_{slope} $\dot{V}O_2$ and WL coefficients with maximal oxygen uptake (table 4) showed weaker character.

Some authors (Beaver 1986; Gaskill 2001) state, that because of large interpersonal differences in chemoreceptor sensitivity threshold, changes in carbon dioxide volume in exhaled air are not always as clear as it was presented in figure 3. Because of that, in order to determine the ventilation threshold with V_{slope} method, the employment of experienced and professional specialists is necessary.

In conclusion, the evaluation of anaerobic threshold with the D_{max} method in swimmers seems to be more useful than the V_{slope} method. Swimmers training is characterized by a large amount of exercises with intensity adequate to D_{max} threshold (at La concentration approximately equal to 4.0 $mmol \cdot l^{-1}$). The modeling endurance abilities is treated in swimming as optimal (Costill and wsp.1992; Platonow 1997; Freitag *et al.* 2000; Issurin *et al.* 2001; Beneke 2003). Undoubtedly the benefit of non-invasive method is the possibility to use it in natural environment, what allows determining the threshold swimming velocity with specific style (Freitag 2000; Pyne 2001).

References

American College of Sports Medicine (1990). The recomended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness in healthy adults. Med. Sci. Sports, 22: 265-274.

Beaver WL, Wasserman K, Whipp BJ (1985). Improved detection of lactate threshold during exercise using a log-log transformation. J Appl Physiol, 59:1936-1940.

Beaver WL, Wasserman K, Whipp BJ (1986). A new method for detecting anaerobic threshold by gas exchange. J Appl Physiol, 60: 2020-2027.

Beneke R (2003). Maximal lactate steady state concentration (MLSS): experimental and modeling approaches. Eur J Appl Physiol, 88:361-369.

Beneke R (2003). Methodological aspects of maximal lactate steady state -implications for performance testing. Eur J Appl Physiol, 89:95-99.

Cheng B, Kuipers H, Snyder AC, Keizer HA, Jeukendrup M, Hesselink M (1992). New Approach for the Determination of Ventilation and Lactate Thresholds. In. J Sports Med, 13: 518-522.

Costill DL, Maglisho EW, Richardson AB (1992). Swimming. London. Edinburgh, Boston, Melbourne, Paris, Vienna: Blackwell Scientific Publication.

Dobbins T, Fallowfield JL (1998). The relationship between the VO_2 deflection point, maximum lactate steady state and V- slope. Conference communications. J. Sports Sci,. 16: 459.

Freitag W (2000). Schwimmen Lernen Und Optimieren. Deutsche Schwimm-Verband.

Gaesser GA, Poole DC (1986). Lactate and ventilation thresholds: disparity in time course of adaptation to training. J Appl Physiol, 61: 999-1004.

Gaskill SE, Ruby BC, Walker AJ, Sanchez OA, Serfass RC, Leon AS (2001). Validity and relibility of combining three methods to determine ventilation threshold. Med. Sci. Sports Exerc, 33: 1841-1848.

Heck H, Mader G, Hess G, Mücke S, Muller R, Hollmann W (1985). Justification of the 4-mmol/l Lactate Threshold. Int J Sports Med, 6: 117-130.

Hughson RL, Weisiger KH, Swanson GD (1987). Blood lactate concentration increases as a continous function in progressive exercise. J Appl Physiol, 62: 1975-1981.

Issurin VB, Kaufman LE, Tenenbaum G (2001). Modeling of velocity regimens for anaerobic and aerobic power exercises in high-performance swimmers. J Sports Med Phys Fitness, 41: 433-40.

Jacobs I, Sjödin B, Kaiser P, Karlsson J (1981). Onset of blood lactate accumulation after prolonged exercise. Acta Physiol Scand, 112: 215-217.

Karlsson J, Jacobs I (1982). Onset of Blood Lactate Accumulation during Muscular Exercise as a Threshold Concept. In. J Sports Med, 3:190-201.

Kindermann W, Simon G, Keul J (1979). The significance of the Aerobic-anaerobic Transition for the Determination of Work Load Intensities During Endurance Training. Eur J Appl Physiol, 42: 25-34.

Loat CER, Rhodes EC (1996). Comparison of the lactate and ventilation thresholds during prolonged work. Biology of Sport, 13: 3-12.

McLellan TM, Jacobs L (1989). Active recovery, endurance training, and the calculation of the individual anaerobic threshold. Med Sci Sports Exerc, 5: 586-592.

Parker J (1989). Wiping Your Swimmers Out. Swimming Technique, 3: 10-16.

Platonow WN (1997). Trening wyczynowy w plywaniu. Warszawa.

Pyne DB, Lee H, Swanwick KM (2001). Monitoring the lactate threshold in world ranked swimmers. Med Sci Sports Exerc, 33: 291-297.

Reinhard U, Müller PH, Schmülling RM (1979). Determination of Anaerobic Threshold by the Ventilation equivalent in Normal Individuals. Respiration 38: 36-42.

Roecker K, Mayer F, Striegel H, Dickhuth HH (2000). Increase Characteristics of the Cumulated Excess-CO_2 and the Lactate Concentration During Exercise. Int J Sports Med, 21: 419-423.

Sjödin B, Jacobs I (1981). Onset of blood lactate accumulation and marathon performance. Int J Sports Med, 2: 23-26.

Slaughter MH, Lohman TG, Boileau RA, Horswill CA, Stillman RJ, Van Loan MD, Bemben DA (1988). Skinfold Equations for Estimation of Body Fatness in Children and Youth. Human Biology, 60: 709-723.

Stegmann H, Kindermann W, Schnabel A (1981). Lactate Kinetics and Individual Anaerobic Threshold. Int J Sports Med, 2: 160-165.

Stegmann H, Kindermann W (1982). Comparison of Prolonged Exercise Tests at the Individual

Anaerobic Threshold and the Fixed Anaerobic Threshold of 4 mmol $\cdot$ l^{-1} Lactate. Int J Sports Med, 3: 105-110.

Tanner JM (1963). Rozwój w okresie pokwitania. PZWL Warszawa.

Tegtbur U, Busse MW, Braumann KM (1993). Estimation of an individual equilibrium between lactate production and catabolism during exercise. Med Sci Sports Exerc, 25: 620-627.

Urhausen A, Coen B, Weiler B, Kindermann W (1993). Individual Anaerobic Threshold and Maximum Lactate Steady State. Int J Sports Med, 14: 134-139.

Wassermann K, Beaver WL, Whipp BJ (1990). Gas Exchange Theory and the Lactic Acidosis (Anaerobic) Threshold. Circulation. 81(suppl II): 14-30.

Wasserman K, Whipp BJ, Koyal SN, Beaver WL (1973). Anaerobic threshold and respiratory gas exchange during exercise. J Appl Physiol, 35: 236-243.