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Original Article

A new approach for the determination of anaerobic threshold: methodological survey on the modified D_{max} method

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ABSTRACT

Siahkouhian M, Azizan S, Roohi BN. A new approach for the determination of anaerobic threshold: methodological survey on the modified D_{max} method. *J. Hum. Sport Exerc.* Vol. 7, No. 2, pp. 599-607, 2012. A wide variety of diagnostic techniques can be found in the literature for anaerobic threshold (AT) assessment. The aim of this study was to investigate if the heart rate (HR) at the modified D_{max} method (Mod-D_{max}) using parallel straight line slope (PSLS) mathematical model and the Narita target heart rate equation was comparable with the HR measured at the AT by the continuous respiratory gas measurements in healthy young girls. Eight (age 19.29±1.70 years) healthy young girls performed an exhaustive treadmill exercise test for determination of the HR at Mod-D_{max} using PSLS model and Narita equation. The AT of the participants was also calculated by the continuous respiratory gas measurements according to the Craig method. There was no significant difference between the HR determined at the Mod-D_{max} method and the HR measured at the AT by the continuous respiratory gas measurements (167±9.22 vs. 165.25±6.32 b/min). Bland and Altman plots revealed a good agreement between the determined HR at Mod-D_{max} and values of the HR measured at the AT by the continuous respiratory gas measurements (95% CI =−20 to+22.8 b/min). According to the results, the Mod-D_{max} using PSLS model and the Narita equation during the exhaustive treadmill exercise test is an accurate and reliable noninvasive alternative to the cumbersome, expensive, and time-consuming invasive methods. Therefore, the Mod-D_{max} method can be used for the determination of AT in healthy young girls. **Key words**: PSLS MATHEMATICAL MODEL, NARITA EQUATION, HEART RATE DEFLECTION POINT (HRDP)

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INTRODUCTION

Different methods as well as a wide range of invasive and non-invasive techniques were used to determination of anaerobic threshold (AT) (Erdogan et al., 2010; Suriano et al., 2007; Bodner & Rhode, 2000). The evaluation of AT through the measurement of blood lactate transition thresholds is commonly performed in sports science assessment and prescription of the optimal training intensities (Fell, 2008; Grazzi et al., 2008; Wonisch et al., 2002).

Researcher have shown that a field methods of assessing the AT can be done from heart rate deflection point (HRDP) in speed-heart rate relationship with accuracy by the visual and computerized methods (Verges et al., 2003; Ghosh, 2004; Bently et al., 2001). Initially, Conconi et al. (1982) developed a field noninvasive test for the determination of the AT using the HRDP which was later modified by Cheng et al. (1992) to the new Distance Maximum (D_{max}) method (Conconi et al., 1982; Cheng et al., 1992; Kara et al., 1996). In the Dmax method, third order curvilinear regression curve was calculated the original HR values vs. the time, two end point of the curve were connected by a straight line and the most distant point of the curve to the line was considered as the HRDP (Conconi et al., 1982). After the straight line formed by the two end points in curve was drown, the formula (Least Square Method) for computing the distance from point to line was used to calculate the distance from each time point on the curve to the line (Cheng et al., 1992).

Craig et al. (2000) was modified the D_{max} method which was later used commonly by the sport scientists (Karatzanos et al., 2010; Folke 2010; Fell, 2008). According to the Craig et al. (2000) procedure, the LT was determined by the point on the polynomial regression curve (based on the mathematical least square method) that yielded the maximal vertical distance to the straight line connecting the first increase in [La−] above resting level and the final [La−] point (volitional exhaustion of subject) (Craig et al., 2000).

Recently a new mathematical model was developed for determination of the HRDP in the GXT exercise protocols by means of "Parallel Straight Line Slope" (PSLS) mathematical model. The nature of this mathematical model, allows for the calculation of HRDP in the upward and downward inflections using HRPC. Moreover, this model requires no formula for computing the distance from point to line (Siahkouhian, 2007).

In addition, Narita et al. (1999) suggested a new target heart rate equation for the adequate exercise training level (AT training) in healthy young boys. They suggested that the resting heart rate and gender are important factors in determining the target heart rate for exercise (Narita et al., 1999). Despite of Narita et al. target heart rate formula, from methodological aspect of view Kara et al. suggested that the minimal HR values for the accurate determination of the HRDP should be obtained between 140-150 bpm (Kara et al., 1996).

Literature revealed that one of the most frequently used methods for the determination of the first threshold is the “V-slope method”. During the early work load (WL) increments in cardiopulmonary exercise testing (CPX), VCO_2 rises as a linear function of VO_2, but as exercise intensity increases, a subsequent increase in this slope occurs. Practically, the VCO_2 versus VO_2 curve is divided into two regions fitted by a two-line regression with the threshold at the interception. Besides the two-line regression model, the threshold may be fixed to the point where the slope changes from a value of less than 1 to ≥1 or where a 45-degree (slope=1) tangent touches the graph (Binder et al., 2008).

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According to this literature, we intended to suggest a new noninvasive and simple method for determination of HRDP using PSLS mathematical model and Narita target heart rate equation as a valid alternative of other direct and indirect expensive methods. Therefore, the aim of this study was to investigate if the HR at the Mod-D_{max} using PSLS mathematical model and the Narita target heart rate equation was comparable with the HR measured at the LT by the continuous respiratory gas measurements in healthy young girls.

MATERIALS AND METHEDOLOGY

Eight healthy young girls [mean (SD) age 19.29 (1.70) years, height 161.57 (5.29) cm, weight 59.71(4.89)] were selected as participants. The mean values of the body composition and physiological characteristics of subjects are listed in Table 1 (Shyamal et al., 2010).

Table 1. Descriptive characteristics of the subjects.

Variables	Age (years)	Height (cm)	Weight (kg)	Fat (%)	LBM* (kg)	RHR# (b/min)	VO_{2max} (ml/kg/min)
Mean±SD	19.29±1.70	161.57±5.29	59.71±4.89	13.38±2.13	51.73±4.28	84.48±7.52	33.36±1.27

**Lean body mass; #. Resting Heart Rate*

They are no regular exercise training at least for a minimum of 12 months prior to participating at the time of testing. Participants were apparently healthy volunteers with no history of cardiovascular disease, orthopedic problems, or other medical conditions that would contraindicate exercise. The information sheet and consent form have been reviewed and signed by the participants. The research protocol has been approved by the Research Ethical Committee in the University of Mohaghegh Ardabili.

Participants attended the exercise-testing lab. on two separate phases. During the first phase participants undertook body composition and physiological tests on three consecutive days. A minimum of 72 h after the initial testing session, during the second phase, the participants completed an AT maximal treadmill test to volitional exhaustion (GXT) with continuous respiratory gas measurements on five consecutive days (Peinado et al., 2011).

The AT of the participants was calculated by the continuous respiratory gas measurements (Ganshorn Medizin Electronic GMBH, Germany) according to the Craig method. In the Craig method the LT was calculated using the modified D_{max} method and determined by the point on the polynomial regression curve that yielded the maximal perpendicular distance to the straight line connecting the first increase in [L]a above resting level and the final [La−] point (Craig et al., 2000).

The second procedure for the determination of the AT was the PSLS mathematical model (Siahkouhian, 2007). Mathematically, in the PSLS model there is only one point in the curve with the same slope as that of the straight line between two end points of the HR-Time curve, which reflects the maximum distance from the straight line (Figure 1). The perpendicular D_{max} between the curve and the straight line during GXT protocols was determined by a special designed computer program written by the authors. Narita et al. equation results [74.8 + 0.76 x (resting heart rate) - 0.27 x (age) + 7.3 x S (male: 0 or female: 1)] were used as first data points of PSLS mathematical model (Narita et al., 1999).

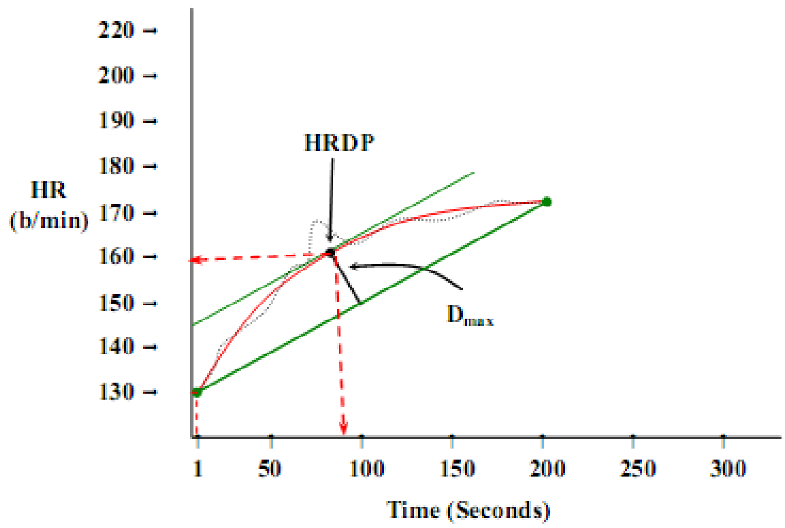

Figure 1. *Determination of the HRDP by PSLS model.*

Peak values for VCO_2, VO_2, RER, HR, Time to and phase of exhaustion were determined from the GXT data (Table 2). All testing protocols for predicting VO_{2max} and AT were performed on a treadmill (Sport ART, Model ¬6150E¬).

Table 2. *GXT Peak values for VCO_2, VO_2, Heart rate, Time to exhaustion, and Phase of exhaustion.*

Variables	VCO_2 (l/min)	VO_2 (l/min)	RER^φ (%)	HR (b/min)	TT ex^® (min)	Phase ex^€ (No)
Mean±SD	2.11±0.41	1.64±0.29	1.29±0.11	192.57±8.79	7.69±1.36	4.36±.42

φ. Respiratory Exchange Rate (Vco2/Vo2 ratio); ®. Time to Exhaustion; €. Phase of Exhaustion.

Data is presented as mean and standard deviations. The Bland and Altman plots and intraclass correlation coefficient (ICC) were used to assess the agreement between the gas measurements and Mod-D_{max} methods.

RESULTS

Bland and Altman plots revealed a good agreement between HR concomitant with the deflection point of the V-slope curve and the HR determined at the Mod-D_{max} method (±1.96; 95% CI = -3.3 to +5.3 b/min; Figure 2).

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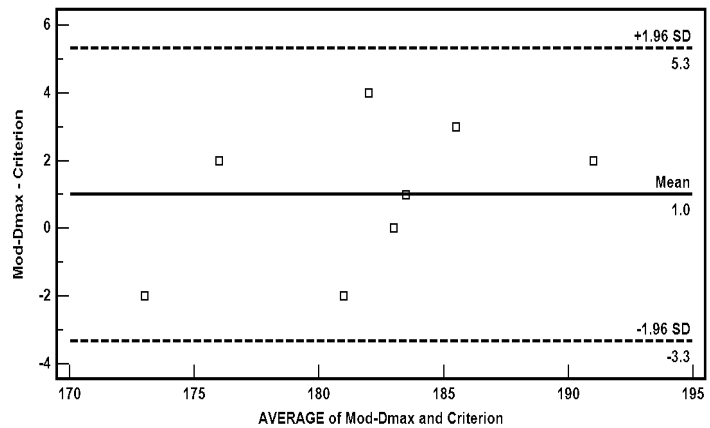

Figure 2. *Agreement between criterion and Mod-D_{max} methods.*

There was high agreement between the AT measured by the criterion (the continuous respiratory gas measurements) and noninvasive Mod-D_{max} methods (167±9.22 vs. 165.25±6.32 b/min; ICC=0.918; Figure 3).

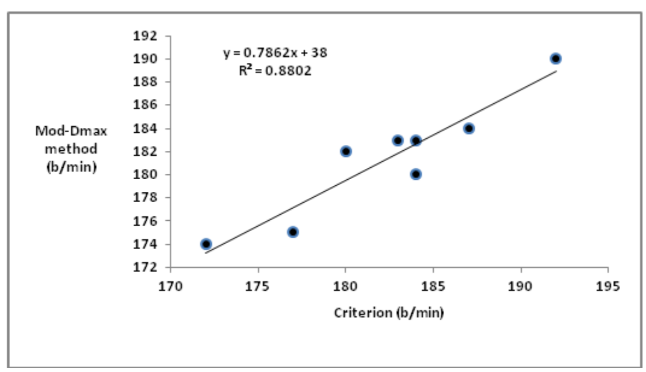

Figure 3. *ICC between the criterion and noninvasive Mod-D_{max} methods.*

DISCUSSION

Our results showed that there was no significant difference between the HR determined at the Mod-D_{max} and HR measured at the AT by the continuous respiratory gas measurements. We also showed a good agreement between the criterion and noninvasive Mod-D_{max} methods.

The expression of the AT in the HRDP literature is varied and has contributed to the challenges of validation. Although some investigators utilized the unconventional multistage protocol created by et al. (1982) most studies applied simultaneous protocols. Several HRDP papers incorporate the Skinner and McLellan theory of energy supply during progressive work and refer to the first breakpoint as the aerobic threshold or the first lactate turn point (Bodner & Rhodes, 2000).

The authors recommended that the slope of the regression line will be affected if it includes the whole HR data points prior to the linear segment in the HR-time curve, which may possibly lead to overestimation of the HRDP. It is recommended that the minimal HR value for the accurate determination of the HRDP should be obtained between 140-150 b/min as in the linear method (Kara et al., 1996). A number of studies have identified the existence of two ventilatory thresholds or LTs during exercise to exhaustion. Numerous terms have been described for an early (first) threshold and a late (second) threshold (Binder et al., 2008).

This first sudden increase in blood lactate (BL) was commonly used as a gold standard for noninvasive threshold determinations by ventilation or gas exchange parameters. A log-log transformation of BL versus VO_2 is a demonstrative way for the detection of the 'first lactate turn point', which may approximate BL levels around 2 mmol/l. With increasing WL above the first LT, the subject reaches a point at which lactate production equals maximal lactate clearance capacity. The 'second lactate turn point' was shown to correlate with maximal lactate steady state (MLSS) and approximates a BL level of 4 mmol/l (Aunola et al., 1992; Vonisch et al., 2002).

The curve of minute VE shows a curvilinear slope pattern with two break points. The first coincides with the 'aerobic threshold', the second with the 'anaerobic threshold'. In a multiline regression model the first curvilinear rise in VE is called the '(first) ventilatory threshold' (VT1). It reflects an increasing ventilatory drive because of excess CO_2, stemming from the buffering of lactic acid by bicarbonate.

One of the most frequently used methods for the determination of the first threshold is the 'V-slope or RER (the ratio of CO_2 output and O_2 uptake) method'. During the early WL increments in cardiopulmonary exercise testing (CPX), VCO_2 rises as a linear function of VO_2, but as exercise intensity increases, a subsequent increase in this slope occurs. Practically, the VCO_2 versus VO_2 curve is divided into two regions fitted by a two-line regression with the threshold at the intersection. Besides the two-line regression model, the threshold in this graph may be fixed to the point where the slope changes from a value of less than 1 to ≥ 1 or where a 45-degree (slope=1) tangent touches the graph.

While major of scientific efforts has been made on the determination of the first ('aerobic') and second ('anaerobic') thresholds (Meyer et al., 2005; Pokan et al., 1998; Brooks, 2000), only few studies in the literature considered the modification of the D_{max} method for the determination of the HRDP by the D_{max} method.

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Fell (2008) undertook a blood lactate transition threshold test to volitional exhaustion according to the methods described by Craig et al. (2000) They showed that the modified D_{max} lactate threshold provides a valid measure of power and heart rate that can be maintained during endurance cycling exercise in veteran cyclists. Their finding supports the use of this threshold measurement for the testing and monitoring of ageing athletes (Fell, 2008).

As we showed the good agreement between HR concomitant with the deflection point of the V-slope curve and the HR determined at the Narita et al. target heart rate equation, the Narita equation results were used as first data points of PSLS mathematical model. It should be noted that in the Narita target heart rate equation, the resting HR, age, and sex of subjects considered as affecting factors.

On the other hand, mathematically, in the PSLS model, there is only one point in the curve with the same slope as that of the straight line between two end points of the HR-Time curve, which reflects the maximum distance from the straight line. Moreover, PSLS model requires no formula for computing the distance from point to line. However, there was no mention of using the PSLS model for determining the HRDP in the literature reviewed.

CONCLUSION

In conclusion, According to the results, the Mod-D_{max} using PSLS model and the Narita equation during the exhaustive treadmill exercise test is an accurate and reliable noninvasive alternative to the cumbersome, expensive, and time-consuming invasive methods. Therefore, The Mod-D_{max} method can be used for the determination of HRDP and therefore AT in healthy young girls.

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