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Review Paper

NON-INVASIVE DETERMINATION OF THE ANAEROBIC THRESHOLD BASED ON THE HEART RATE DEFLECTION POINT

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Abstract. *One of the numerous methods for determining the upper limit of individual aerobic metabolism is the Conconi test. It is a simple, non blood-based test, which can give an indication of an athlete's condition or state of training. It is an extremely reliable and powerful predictor of performance in an aerobic exercise. It is based on the correlation between the anaerobic threshold and a deflection point in the heart rate during an incremental exercise test. The reason why some authors have questioned the validity of the concept is the fact that no uniform HR response could be expected from all individuals during incremental exercise. Although physiological mechanisms behind the heart rate deflection point phenomena have still not fully been analyzed and there are still some open questions regarding this method being used to determine the anaerobic threshold non-invasively, in practice it is an easy-to-apply and accurate method to use on subjects presenting a heart rate deflection.*

Key words: *Anaerobic threshold, the Conconi test, Heart rate deflection point*

INTRODUCTION

In the last few decades, physiologists have developed numerous methods for determining the upper limit of an single aerobic metabolism. The term anaerobic threshold was first introduced to describe a non invasive single break-point model of the transition from aerobic to anaerobic metabolism (Wasserman & McIlroy, 1964).

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Anaerobic threshold (AT) is a frequently used term that sometimes causes a little confusion. It is defined as the physiological point during exercise at which muscular lactate production exceeds the rate of lactate oxidation, and as a result, lactate shows up in the system and may be balanced or not, depending on the intensity of the exercise (in relation to the RCP or the LTP2).

This means that the muscles start producing more lactic acid than the body can process. This, in other words, hinders the ability to perform at optimal intensity over an extended period of time (Billat, 1996).

From a theoretical point of view the term anaerobic is misleading, it leads people to think that everything up to that point is aerobic and everything after that point is anaerobic, which is incorrect. In reality, we always use both aerobic and anaerobic metabolic pathways to produce energy, but the intensity (and glycogen/glucose availability) will dictate how much of each we will use. Hypothetically, there are 3 phases of the energy supply process that contribute to the work necessary to progress from low to high intensity exercise. These phases are identified by two transitions or breakpoints (Skinner & McLellan., 1980), a claim which is supported by the shuttle hypothesis developed by Brooks (Brooks, 1986). The energy supply in the first phase (lactate production and oxidation are balanced on the muscular level and no lactate shows up in the system) is derived entirely from aerobic metabolic processes. The first breakpoint, the beginning of phase II, is designated as the 'aerobic threshold' (originally termed "anaerobic threshold" – AT by Wasserman et al. 1964 – which led to great confusion), and is characterized by a disproportionate increase in VE/VO_2 without an increase in VE/VCO_2 and an increase in blood lactate concentration. This point is also defined as the first lactate turn point (LTP_1). So, even though this has led to an increase in blood lactate levels, it is still possible to maintain the ability to perform at optimal intensity over an extended period of time. This is possible because the lactic acid which is produced in the muscle can shift from the working muscles to the circulatory system and is then used by different muscles and organs, such as the heart. Phase III is above the 'anaerobic threshold' and is characterized by an increase in both VE/VO2 and VE/VCO2 – the so-called respiratory compensation point (RCP) (Skinner & McLellan., 1980) and by the second breakpoint in the blood lactate concentration (LTP_2). This happens because the working muscles start to produce more lactate than the whole body is able to process. It is usually around 4 $mml \cdot l^{-1}$, and is defined as the second lactate turn point (LTP_2) (Aunola & Rusko, 1992; Davis et al., 1983). This second turn point may be defined as the highest constant workload in which the lactate release into and removal from the blood is in equilibrium (Aunola & Rusko, 1992), in the so-called maximal lactate steady state (MLSS) (Beneke, 1995; Beneke, Heck, Schwarz, & Leithäuser, 1996; Hofmann, Bunc, Leitner, Pokan, & Gaisl, 1994a).

Because of this, a better term to define the phase would be threshold defined by the measured parameter, e.g. lactate, ventilation or heart rate and the point of time (LTP_1, LTP_2, $VETP_1$, $VETP_2$, $HRTP_2$).

Nevertheless, the anaerobic threshold is calculated by determining the relationship between the blood lactate and the running speed, or by determining the alterations in the selected respiratory gas exchange variables. Prolonged exercise of an intensity above this point will cause an abrupt increase in blood lactate levels. The most accurate way to determine this point is via a graded exercise test in a laboratory setting. But, in cases where this is not possible, the Conconi test is considered to be a very popular and practical test for the non-invasive determination of the anaerobic threshold (Conconi, Ferrari, Ziglio, Droghetti, & Codeca, 1982; Conconi et al., 1996).

THE CONCONI TEST

The Italian biochemist Francesco Conconi (Conconi, Ferrari, Ziglio, Droghetti, & Codeca, 1982) developed a simple, non blood-based test, in1982, which can give an indication of an athlete's condition or state of training. It is an extremely reliable and powerful predictor of performance in aerobic exercise. Also, this test is very popular because it is an easy, inexpensive and non-invasive method to determinate the anaerobic threshold.

The Conconi Test Procedure

After a usual warm-up lasting around 15 - 30 min, the subject begins the test with a work intensity that is low to moderate for his abilities. Conconi mainly tested trained athletes so he initially suggested a starting running speed of 12-14 km/h. But depending on the physical status of the subjects, the starting running speed should not be too slow or too fast from the beginning (lower than 70% HR_{max}). The work intensity must be increased slightly and continuously (to avoid activation of the lactic acid mechanism), in such a way as to increase the HR by around 5 beats per minute (not more than 8 according to Conconi). The test must be paced, especially if inexperienced subjects are involved. The speed of movement or (the load) is continually increased until exhaustion. The gradual continuous progression can be subdivided into as many intervals as necessary to collect enough data points to allow for good test analysis. During the test, the HR is monitored continuously and the speed for each interval is calculated based on the elapsed interval.

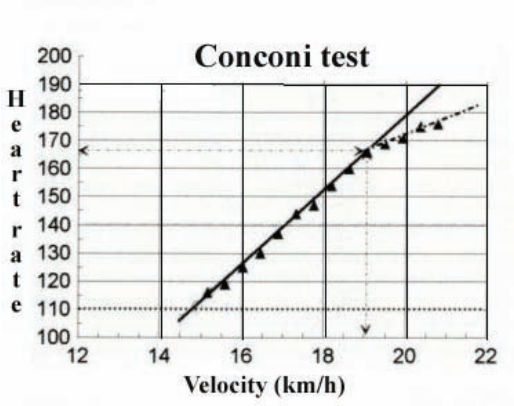

Fig. 1. The relationship between the running speed and the heart rate of a long-distance runner (best time for 10.000 m, 29 min:04 s).

This method has been modified for various groups of subjects and sports activities (Ballarin et al., 1989; Conconi et al., 1988, 1996; Grazzi et al., 1999; Cellini et al., 1986; Droghetti et al., 1985) by the Conconi work group. Because of its popularity, in practice the test has been modified for several applications (Conconi et al., 1996; Ballarin et al. 1989; Mafufuleti, Sjodin, & Eklblom, 1987; Petit, Nelson, & Rhodes, 1997; Pokan et al., 1993, 1999; Hofmann, Peinhaupt, Leitner, & Pokan, 1994; Thorlund, Podolin, &

Mazzeo, 1994). This test is performed by subjects with a wide range of athletic abilities: from sedentary individuals, trained and untrained children and adults to elite athletes of various sports. Also this test can successfully be performed in the laboratory as well as outdoors.

Conconi et al. (1996) modified their original protocol whereas the increases in speed were based on time rather then distance. In addition, the increases in speed were step-like and in the new protocol they were changed to a uniform increase in speed (ramp-like exercises). This modification was made to allow for an easier heart rate adaptation to the increases in intensity of the exercise. Avoiding a sudden increase in speed will allow the cardiovascular system to adapt efficiently to the successive increase in work intensity and will allow the reduction of the activation of anaerobic mechanisms.

The authors also adapted their protocol for the cycle ergometer tests (Conconi et al., 1996). During running, the speed is increased by increasing cadence and length of stride. So they suggested an increase in cadence and force and not only force alone during the cycling protocol, which would resemble actual cycling conditions when cyclists reach their maximal speed at a cadence exceeding 160 revolutions per minute.

Factors that influence the test

Several factors, such as the physical status of the subjects, the warm-up procedure and the duration of the test can influence the speed/heart rate relationship. Before the test, the subject should be well rested and should not performed any difficult physical work 48 hours prior the test. In addition, the subjects should not drink any coffee or take any medication. With an adequate warm-up procedure, athletes showed a significantly higher maximal HR (HR_{max}) than without a warm-up procedure (Conconi et al., 1996). This is especially true for the highly trained athletes.

In tests of shorter duration, larger increases in speed will lead to higher average increases in heart rate. The test with larger increases in HR showed a speed/heart rate relationship that was displaced to the right compared to smaller heart rate increases; in addition, the HRDP and HR_{max} are lower, and the speed of the heart rate deflection is slightly higher (Conconi et al., 1996).

THE HEART RATE DEFLECTION POINT

Conconi stated that the anaerobic threshold correlated to a deflection point in heart rate during an incremental exercise test. The heart rate was said to increase in a linear fashion in relation to the exercise. However, Conconi found that for all their tested subjects, including those in a follow-up test (Conconi et al., 1996), at the near maximal exercise intensities, the heart rate reached a point above which work intensity increased more than the heart rate (Conconi, Ferrari, Ziglio, Droghetti, & Codeca, 1982). The fact that the HR response to incremental testing does not always indicate a strictly linear response was firstly observed by Brooke & Hamley (Brooke & Hamley, 1972). Their findings showed that some individuals presented an S-shaped HR/workload relationship. This HR/physical workload curve was characterized by 3 distinct sequential phases: an anticipatory phase, a linear phase where the slope of the HR was consistent, and a curvilinear phase where the slope of the HR/workload decreased and deviated from the linear trend

(Brooke & Hamley, 1972). It was hypothesized that these 3 sequential phases are concurrent with the 3 phases of energy supply.

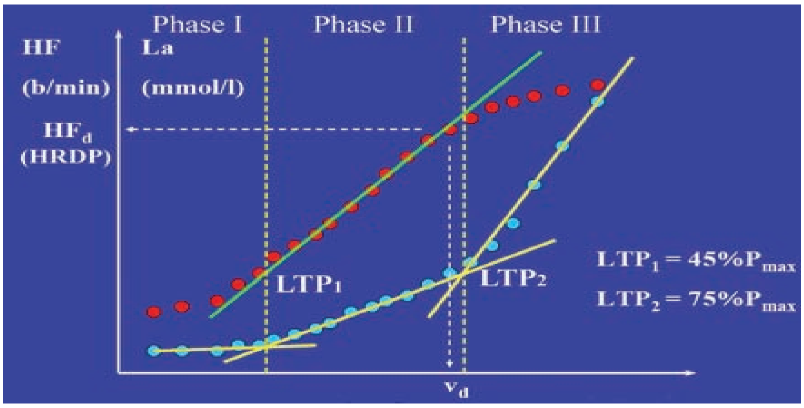

Fig. 2. The HR/physical work curve with 3 distinct sequential phases
Unpublished picture, courtesy of prof. Hofmann.

The point where work intensity increases more than the heart rate is most usually termed as the heart rate deflection point (HRDP) (deWit et al., 1997; Jones & Doust, 1995; Vachon, Bassett, & Clarke, 1999), but it also appears in literature as the heart rate brake point (Ribero et al., 1985), heart rate threshold (Bunc et al., 1994; Thorlund, Podolin, & Mazzeo, 1994; Hofmann et al., 1994a, 1994b, 1994c) or heart rate turn point (Pokan et al., 1998, 1999).

Attempts have been made to compare this heart rate deflection point to other turn points and threshold concepts. Several authors have found a significant correlation between the HRDP and the lactate anaerobic threshold (Pokan et al., 1999; Bunc et al., 1995; Hofmann, Leitner, & Gaisl, 1992; Hofmann et al., 1994a), as well as between the HRDP and the ventilatory threshold (Bunc & Heller, 1992; Bunc et al., 1995).

But unlike Conconi, not all of the researchers could detect a HRDP in all of the cases and this is one of the reasons why some authors have questioned the validity of the concept (Jones & Doust, 1995, 1997; Coen, Urhausen, & Kindermann, 1988; Bourgois & Vrijens, 1998; Francis et al., 1989; Heck et al., 1988; Tokmakidis & Leger, 1992). The main point of criticism was that the deflection of the HRPC necessary to detect the "threshold" could not be found in a certain number of subjects (Hofmann et al., 1997). Heck et al. (1988) presented a review of literature showing between 7 and 100% of the subjects with no detectable heart rate deflection point. Hofmann et al. (1997) cautioned that although the HRDP may be useful from a training prescription perspective, universal applicability may not be warranted since the HRDP was not observed in 6.2% of a total of 227 young men. And although 93.8% of the subjects of this study showed a deflection of the heart rate performance curve (HRPC), an inverse deflection of the HRPC was found in 7.9%, and only 86% showed a deflection of the HRPC similar to the one presented by Conconi (Conconi, Borsetto, & Casoni, 1992), which seems to be the regular behavior of the HRPC (Brooke & Hamley, 1972).

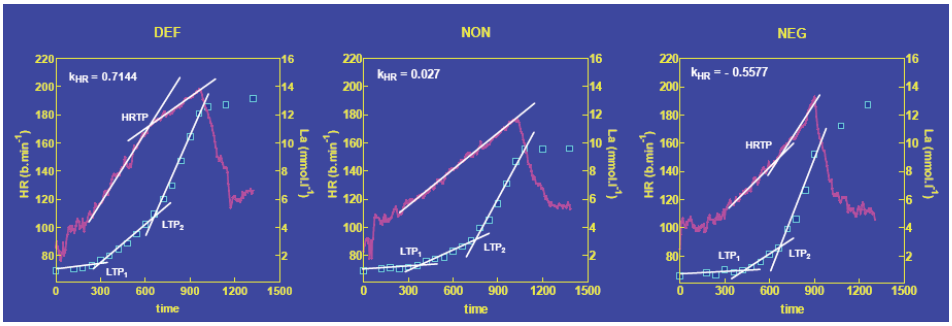

Fig. 3. Examples of regular deflection according to Conconi et al, no deflection at all, and an inverse deflection of the heart rate performance curve (HRPC). Unpublished picture, courtesy of prof. Hofmann.

No uniform HR response could have been expected from all of the individuals during incremental exercise. Three different HR response patterns (Fig.3) have been identified during different activities in various groups of subjects (Hofmann et al., 1996, 1997, 2005; Pokan et al., 1998a, 1998b). Also older subjects and cardiac patients show a higher degree of non-regular HR response (linear or inverted above LTP_2). In the cases with non-regular HR response, the use of a $\%HR_{max}$ concept would overestimate the subject's threshold systematically /52/. Still, the HRTP was not significantly different from the LTP_2 (Hofmann et al., 1997).

Methodology of the HRDP assessment

Although several methods which are used to objectively determine the HRDP are available, many researchers are still using a subjective approach (Cellini et al., 1986; Ribero et al., 1985; Jones & Doust, 1997). Even though it is possibly not the most accurate method, it is the most practical. When this method is used it is necessary that a visual HRDP analysis be carried out by experienced observers.

A more objective approach to determine the HRDP is by means of mathematical modeling, regression techniques including simple linear regressions (deWit et al., 1997), 2-compartment linear regression models (Bunc et al., 1995; Kara et al., 1996) and mono-segmental exponential and bi-segmental logarithmic analyses (Tokmakidis & Leger, 1992).

The computer aided linear regression break point analysis is considered to be one of the most sensitive methods for the assessment of HRDP (Hofmann, Leitner, Gaisl, & Neuhold, 1990). The regression lines used to calculate HRDP are applied between the first lactate turn point (LTP_1) and the power output at maximal HR.

The direction and degree of HRPC deflection was calculated by a second degree polynomial representation of the HRPC between the LTP_1 and P_{max}, satisfying the condition of the smallest number of errors. Tangents of various points between the LTP_1 and maximal power output were calculated to give a value called 'factor k_{HR}', which was used to subdivide the subjects into subgroups according to their type of deflection. A regular deflection as describes by Conconi et al. (Conconi, Ferrari, Ziglio, Droghetti, & Codeca, 1982; Conconi et al., 1996) would have a positive k_{HR} value and an inverse deflection would have a negative k_{HR} value (Pokan et al., 1993).

Physiological basis of the HRDP

Physiological mechanisms behind the heart rate deflection point phenomena have still not been fully explained. However, myocardial functions, the influence of catecholamines and neural systems, as well as of potassium levels have been suggested as possibilities.

Myocardial function was expressed as the left ventricular ejection fraction (LVEF). The change in the increased LVEF is significantly related to the second lactate turn point and HRDP (Pokan et al., 1993; Hofmann et al., 1994). But, even though it is obvious that the myocardial function is related to the HR response pattern, any cause and effect relationship could not be explained and it is still an unanswered question.

A significant relationship was found to exist between the plasma catecholamine responses of both adrenaline and noradrenaline and the HRTP and the LTP_2. Although they are obviously the link between both the HR and LTP_2 phenomenon, they do not influence the typical individual pattern (Pokan et al., 1995).

There is also a hypothesis that the increased release of potassium might influence the function of the myocardium (Hofmann et al., 1999). Changes in blood potassium levels between LTP_2 and the maximal power output suggests that potassium might play a role in the individual HR response during incremental exercise but it still does not explain the differences in a diminished HR response below LTP_2 in subjects with non-regular HR responses. At the moment the main hypothesis is that the sensitivity or number of beat-1-adrenoceptors is the primary cause for the differences in the HR response during incremental ergometer exercise (Hofmann et al., 2005).

Although there are still some open questions regarding this non-invasive method used to determine the anaerobic threshold, it is an easy-to-apply and accurate method used for subjects presenting a heart rate deflection.

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NEINVAZIVNO ODREĐIVANJE ANAEROBNOG PRAGA NA OSNOVU DEFLEKSIJE SRČANE FREKFENCIJE

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Conconijev test predstavlja jednu od mnogobrojnih metoda za određivanje anaerobnog praga. On je razvio jednostavnu metodu za procenu nivoa utreniranosti sportiste bez analiziranja krvi. Takođe, ova metoda je veoma pouzdana i predstavlja jak prediktor aerobnih sposobnosti sportiste. Ova metoda je zasnovana na povezanosti između anaerobnog praga i trenutka defleksije srčane frekvence prilikom testa sa postepenim povećanjem intenziteta. Glavni razlog zbog kojeg su pojedini autori izrazili svoje sumnje u validnost metode, predstavlja činjenica da se regularan odgovor srčane frekvence tokom testa sa postepenim povećanjem intenziteta ne može očekivati u svim slučajevima. Pored toga što fizioloski mehanizmi, koji stoje iza fenomena momenta defleksije srčane frekvence nisu u potpunosti razjašnjeni, postoje još uvek otvorena pitanja u vezi sa ovom metodom za neinvazivno određivanje anaerobnog praga. Zbog svoje preciznosti i jednostavne primene, ona predstavlja veoma popularnu metodu u praksi, kod ispitanika koji imaju regularan odgovor srčane frekvence.

Ključne reči: *Anaerobni prag, Conconi test, Defleksija srčane frekvence*