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Energy expenditure, aerobic energy cost and anaerobic energy cost

Gasto energético, custo energético aeróbio e custo energético anaeróbio

Victor Machado Reis [1,2]

Abstract – The difficulty involved in the calculation of the energy cost during most of the physical activities is related to the mixed nature of the energy elicited. Therefore, it is important to know under which exercise conditions it is possible to perform such measurements and under which conditions it is not. Several terms are often associated with this line of research, such as: energy expenditure, caloric expenditure, or energy cost. The objectives of the present study were to review the methods typically used to assess energy cost and to suggest a more precise nomenclature when teaching or conducting research on these theme. The use of expired O_2 to quantify aerobic energy seems undisputable. As to anaerobic lactic energy, more studies are required, using both blood lactate energy equivalent values and accumulated oxygen deficit. The term energy expenditure should be used only when energy release is almost fully aerobic and when direct O_2 measurement can be performed during exercise. In every other exercise conditions, the term energy cost is more suitable, as it cannot be directly assessed. Whenever energy cost is mentioned, it should be accompanied by the identification of whether aerobic fraction, anaerobic fraction, or total energy cost is considered.

Key words: Aerobic energy cost; Anaerobic energy cost; Energy expenditure; Energy Metabolism; Lactic Acid; Oxygen Consumption.

Resumo – *A dificuldade de cálculo do custo energético durante a maioria das atividades físicas reside no fato da solicitação energética ser mista. Importa saber identificar em que condição é possível medir ou estimar o custo energético e em que condição tal não é possível. Existe uma utilização de diferentes termos associados a esta temática como, por exemplo, gasto energético, gasto calórico, dispêndio energético, ou custo energético. O objetivo deste artigo foi recordar os métodos mais populares de quantificação do custo energético e propor um maior rigor na nomenclatura a usar no ensino e investigação. Parece pacífica a utilização do O_2 expirado como quantificador da energia aeróbia. Quanto à energia anaeróbia láctica, devem prosseguir estudos usando o défice de oxigénio acumulado ou o equivalente energético de lactato. O termo "gasto energético" deverá ser reservado a situações em que o exercício é quase exclusivamente aeróbio e em que é possível medir diretamente as trocas gasosas durante o esforço. Em todas as restantes situações, deverá ser usado preferencialmente o termo "custo energético", porquanto o mesmo pode ser estimado, mas não medido diretamente. Quando usado o termo "custo energético" o mesmo deve ser complementado com a identificação se tratamos da fração aeróbia, da fração anaeróbia ou de ambas.*

Palavras-chave: *Consumo de oxigênio; Custo energético aeróbio; Custo energético anaeróbio; Gasto energético; Lactato; Metabolismo energético.*

1 Universidade de Trás-os-Montes & Alto Douro, Vila Real, Portugal.

2 Centro de Investigação em Desporto, Saúde & Desenvolvimento Humano, Vila Real, Portugal

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INTRODUCTION

The difficulty to assess the energy cost during most physical activities is related to the mixed bioenergetic nature of the effort. Therefore, it is important to be able to identify under which conditions it is possible to measure or estimate the energy cost and under which conditions it is not. Moreover, there is an imprecise and even abusive use of different terms that are associated with these issues, such as energy expenditure, caloric expenditure, and energy cost. Among these, the use of caloric expenditure should be avoided. In fact, it does not seem appropriate to associate a unit of measurement (calorie) with the concept itself. The unit of measurement may vary for the same concept or entity. Using the term caloric expenditure would be equivalent to using metric length or volume in liters. The use of the term energy expenditure is appropriate under certain conditions of exercise. However, the use of energy expenditure should not be confused with energy cost since they may be different entities. Indeed, the two terms may be different both conceptually and operationally. Conversely, the use of any of these concepts should be accompanied by a specification of which energy source is at stake (aerobic or anaerobic).

The objectives of the present article were to review the methods typically used to assess energy cost and to suggest a more precise nomenclature when teaching or conducting research on these theme.

ENERGY COST VS. ENERGY EXPENDITURE

In my opinion it is possible to differentiate the two entities. The term energy expenditure is appropriate when the method of assessment allows a direct and precise quantification. In these cases, the source of error is solely the technological error associated with the instruments that are used. When gold standard instruments are used, the total error may be regarded as negligible. Hence, only when the aerobic fraction of energy release is measured with direct VO_2 and only when the anaerobic fraction is negligible, it is licit to consider that the energy expenditure is truly assessed. Therefore, a first limitation for the term energy expenditure is present herein, as most of the effort in sports or in general physical activity include a considerable anaerobic energy release. This is why I believe that the expression energy cost is more accurate and appropriate to use on every type of physical effort. Energy cost represents the total amount of energy required to perform a specific task and it may include both aerobic and anaerobic fractions of energy release. In this case, the aerobic fraction may be directly assessed without error using VO_2 measurement, whereas the anaerobic fraction can only be estimated indirectly. Since the anaerobic fraction is an estimate, it includes other sources of error besides the technological measurement error. As such, the term energy expenditure is appropriate only when the following assumptions are met: i) the exercise intensity is constant and the exercise duration is enough for VO_2 to attain a steady-state; ii) a direct VO_2 measurement is performed; iii) the anaerobic fraction of energy release is limited to the initial O_2 deficit. When these three assumptions are not met, the term energy cost should be used. And even when the aforementioned assumptions are met, the term energy cost may be appropriate. When VO_2 is measured during recovery (as in between series of exercises or between exercises or even at the end of a training session), the aerobic energy release is not quantified directly and without error. In fact, in post-exercise periods the VO_2 reflects a sum of different physiological mechanisms addressed to make the body to return to normal resting conditions. Therefore, post-exercise VO_2 does not quantify the energy cost of exercise let alone the true energy expenditure during exercise.

For all the reasons, I do consider energy cost as the most precise and comprehensive term. Therefore, this term will be used in the next sections of the present article.

AEROBIC ENERGY COST

Aerobic energy cost is usually assessed by direct calorimetry based on the VO_2 measurement in the expired gases during exercise. The use of VO_2 as quantification of the aerobic energy cost requires that the VO_2 remains constant. In practical terms, this means that the assessment of the aerobic energy cost is more precise the lower the exercise intensity and the higher the exercise duration. In general, it is accurate to assess the aerobic energy cost using VO_2 measurement in exercises at intensities below the lactic threshold lasting longer than 3 min and in exercises at intensities between the lactic threshold and the peak VO_2 lasting longer than 5 min (or the duration that is necessary to attain VO_2 steady-state).

In running, cycling, or swimming, the VO_2 on-kinetics is well described, as well as in other types of exercise (rowing, walking). However, this does not apply to most other types of physical activities. In addition, the exercise intensity that corresponds to the exponential and fast rise in the blood lactate is also poorly understood in most of the physical activities. In running or cycling, the lactate threshold is typically comprised between 75 and 80% peak VO_2. Rocha et al.[1] performed a careful study and concluded that the lactate threshold could be around 32% of 1-RM in the inclined leg press exercise (45°). Moreover, the concept of maximum VO_2 is poorly understood in exercises other than running, swimming, or cycling (i.e., resistance exercises). Therefore, it is important to investigate the oxidative limit of each and every exercise to improve the knowledge on the bioenergetics of that same type of exercise.

ANAEROBIC ENERGY COST

The methods to assess anaerobic energy release during exercise are less precise than those previously discussed. A variety of indirect measures has been used but none of them is fully accepted. A gold standard measure to quantify alactic and lactic energy turnover during exercise would require muscle biopsies, thereby enabling the direct quantification of the muscle energy sources (i.e., high-energy phosphates and glycogen) and accumulation of muscle metabolites (i.e., lactate). The limitation of this technique is related to the fact that only a small portion of body muscles are suitable for such analysis. In addition, there is often need to collect various samples of muscle at different depths to obtain a representative sample of the muscle to be studied, especially in terms of the fiber composition[2]. Conversely, the use of this technique is not recommended because it is a highly invasive procedure.

The measure most often used to estimate the lactic fraction of anaerobic energy release during exercise is the energy equivalent of the post-exercise peak blood lactate. This measure is typically complemented by a pre-assumed value of the alactic fraction. Such value is estimated based on the fast constant of the VO_2 on-kinetics, which may vary according to the type of exercise, being able to attain as much as 36.8 $mlO_2{\cdot}kg^{-1}$ according to di Prampero et al.[3] The pioneer studies by Margaria et al. [4], subsequently followed by Cerreteli et al.[5] and later complemented by di Prampero[3], contributed to the definition of an energy equivalent for the accumulation of post-exercise lactate in the blood that could be used to quantify lactic energy release during exercise in running or swimming exercises (comprised between 2.7 e 3.3 ml O_2 $kg^{-1}{\cdot}mM^{-1}$). It is worth to mention that this value reflects an energy equivalent of the lactate accumulation instead of a direct measure of the lactate formation during exercise[3,6]. Therefore, at submaximal exercise intensities, especially at those when the blood lactate concentration may be maintained for a certain time (irrespective of being below or above the 4 mM threshold), it is unnecessary to account for the lactic contribution to the overall energy cost. Indeed, under these exercise conditions, the lactate accumulated in the blood is probably due to an early lactate formation in the initial stage of the exercise[6]. Subsequently, VO_2 rises and it attains a steady-state, being able to fully meet the energy demand. Despite the several sources of error included in this method that may be checked in the literature[7]. I believe that its main limitation is the fact that the energy equivalent of lactate in the blood is only valid for running, cycling, and swimming exercises. It has been also used in resistance exercises by Scott[8]. However, there is no experimental evidence to confirm the energy equivalent of blood lactate for this type of exercise.

The alternative to the lactate energy equivalent and the assumption of the alactic energy release during exercise is the accumulated O_2 deficit method. This is a measure including both components, lactic and alactic, and it does not require any invasive technique. Its determination is possible from direct measurement of expired gases and it allows the quantification of aerobic and anaerobic fraction of energy release related to the overall energy cost of exercise[9]. This method, seldom used in resistance exercise[10], has been used for more than 20 years in cyclic human movements such as running[11,12], cycling[13], and swimming[14], and it is considered by some as the most realistic measure of the anaerobic energy during exercise[15]. Similarly to other physiological models and measurement techniques, the theoretical assumptions on which the measure is founded are not easy to prove. However, they do not differ from a number of assumptions often used in exercise physiology; such as the assumption that expired gases do reflect the metabolism of active muscles.

CONCLUSION

To me it seems clear that the use of expired VO_2 to assess aerobic energy cost is a must. However, we should focus more on the way the measurement is performed, especially in terms of the O_2 on-kinetics as a function of intensity, duration, and other parameters of the exercise. The assessment of post-exercise VO_2 is only of interest when comparative purposes are at stake. However, it is not of interest in terms of the characterization of the bioenergetics associated with a certain type of physical activity; as post-exercise VO_2 does reflects simultaneously aerobic and anaerobic pathways and it involves various mechanisms used by the body to return to a resting metabolic state. Hence, it does not quantify the energy turnover during exercise.

As to the estimation of the lactic anaerobic energy, it is my opinion that further studies using both the accumulated O_2 deficit method and the blood lactate energy equivalent are required. However, these should be methodological studies including the analysis of various combinations of each method to unravel which is more appropriate for different types of exercise. The alactic fraction of energy release can still be investigated by the modulation of the VO_2 on-kinetics (O_2 deficit) and off-kinetics (O_2 debt). However, these should be complemented by precise quantifications of the muscle mass involved in each and every type of exercise (once the alactic fraction estimate is highly dependent on this assumption).

In my opinion, one should always prefer the use of the term energy cost, preferably complemented by the indication of the metabolic pathways involved in the exercise (aerobic or anaerobic). The expression energy expenditure has a very limited field of application and it is often used in an inappropriate manner.

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Endereço para correspondência
Victor Machado Reis
Universidade de Trás-os-Montes & Alto Douro
Parque Desportivo da UTAD, Apartado 1013
5001-801 Vila Real. Portugal
E-mail: vreis@utad.pt