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CORRELATIONS BETWEEN OXY-HEMOGLOBIN AND RESPIRATORY EXCHANGE RATIO IN THE QUADRICEPS DURING THE EARLY PHASE OF EXERCISES

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The early stage of exercises is crucial in sports training; however, its physiological mechanism is still unclear. The hemodynamic response was reported to be associated with respiratory exchange. Here, we aimed to explore the relationship between oxy-hemoglobin concentration change (HbO_2) and respiratory exchange ratio (RER) during the early phase of exercises. Sixteen athletes of middle-distance race were selected from Wuhan Institute of Physical Education to conduct intermittent exercises on MERCURY4.0 at 80% VO_{2peak} intensity. Multiple physiological parameters were acquired by use of a near-infrared spectroscopy muscle oxygen monitor, a Cardiopulmonary Function MAX-II and a P-Lar, including HbO_2, RER and others. A significant correlation was found between RER and HbO_2 in quadriceps muscle in the thigh during the early phase of exercises. Thus, NIRS is capable of supervising sports training in terms of HbO_2, which actually acted as an interpreter of RER change.

Keywords: Near-infrared spectroscopy; intermittent exercises; respiratory exchange ratio; oxy-hemoglobin.

1. Introduction

NIRS is capable of real-time monitoring of muscle oxygenation in the local skeletal muscles, including oxy-hemoglobin concentration change (HbO_2), deoxy-hemoglobin concentration change (Hb) and blood volume (BV). Especially when the relationship between energy metabolism of local skeletal muscle during exercises and HbO_2 is explored, NIRS is served as a new method of monitoring local skeletal muscle physiological status for sports training. However, NIRS, as a new method, has not been fully accepted to be utilized in monitoring local skeletal muscle for sports training. Since the possibility of NIRS in measuring oxygen supply in tissue *in vivo* was proposed by Jobsis in 1977, many studies were carried out on its feasibility, reliability and validity.[3–6] In the past decade, the application research of NIRS in sports physiology has been extensively unfolded.

Currently, RER and blood lactic acid (LA) are most widely used to evaluate physiological metabolism in athletes. RER and LA reflect the metabolic state of whole body, and thus could not be used in monitoring local skeletal energy metabolism. In sports training, coaches are usually concerned on some specific skeletal muscles in terms of aerobic capacity or anaerobic ability during sports training. To design an optimal load in aerobic training for specific skeletal muscles, coaches required a new index for evaluating the local skeletal muscles. Previous research showed that HbO_2 was provided as a sensitive index to interpret the local energy metabolism; hence, it is not unreasonable to expect that it can be served as an effective index to evaluate the physiological state of local skeletal muscles.

Our previous study[7] has found an inflexion point in HbO_2 curve, named inflexion point of oxy-hemoglobin dissociation (ODIP), which was associated with RER in local skeletal muscles during sports training. Similar manifestation was found in both the leg and the arm during the early phase of exercises, although there might be some differences between the leg and the arm. For instance, Satoshi Muraki *et al.* in 2003[16] has reported an authentic lower capacity of oxygen utilization in the triceps muscle of the arm compared with quadriceps muscle of the thigh during incremental exercises. Commonly, sufficient oxygen supply and significant HbO_2 decrease both indicate that there is enough capacity of oxygen utilization during the early phase of exercises. Accordingly, there might be some correlation between HbO_2 and RER in sports physiology mechanism, possibly in the early stage of exercises. Here we devote this article to testing this hypothesis.

2. Experiments

2.1. *Subjects*

Sixteen adult male athletes (18 ± 2.5 years old, 60 ± 5.2 kg weight) of middle-distance race from Wuhan Institute of Physical Education are invited to do the experiment.

2.2. *Methods*

The subjects were instructed to do intermittent exercises to acquaint themselves with the parameters, followed with load increments, which are frequently used in sports training, on MERCURY4.0. In order to measure athletes' VO_{2peak}, they were required to take steadily-increasing exercises one week before. This type of exercise was designed with an initial speed of 15 km/h, and a steady increment of 2 km/h every 3 min. Cardiopulmonary Function MAX-II was adopted to monitor the subjects' VO_2 until the peak of VO_2 (VO_{2peak}) is reached. In the formal tests athletes carried out intermittent exercises with the load of 80% VO_{2peak} on MERCURY4.0. All equipments were started simultaneously right before the experiment. In the experiment, subjects first took a rest for 2.5 min, then took four 6-min exercises on MERCURY4.0, and finally, took a 10-min rest. There was a 2-min rest in between every 6-min exercises.

2.3. *Data acquisition*

A three-wavelength near-infrared spectroscopy muscle oxygen monitor[1,2] was fixed on the surface of musculus quadriceps femoris (10 cm above knee joint). At the same time, MAX-II and P-Lar were used too. The data of HbO_2, Hb, BV, VO_2, VCO_2, RER and HR were acquired. All equipments were started and shut down simultaneously.

2.4. *Accuracy analysis*

There are some factors that introduce error:

(1) Simultaneity in the measurement of all equipments. Each equipment was operated by one person. By oral directions, all operators were instructed to perform the operations on the equipments, including starting or shutting down the equipments. The error on the simultaneity of the measurements was based on the reaction speed of individuals. However, this error was less than 1 second, which was negligible for our measurements that last for more than 2000 seconds.
(2) Individual differences of subjects. Although it is inevitable too, this error was almost eliminated by performing comparison among the measured data for each subject.

2.5. *Data processing*

Comparisons are based on figures with common axes drawn according to data. All statistical analyses were performed by using SPSS software.

2.5.1. *Significance of figures with common axes*

There were several limitations in traditional figures when previous researchers used to compare between indexes. The traditional figures were commonly shown with disunities of axes and data densities, long distance and different scales between curves, and no uniform reference lines available. Thus, it was not easy to perform precise comparisons between RER and HbO_2. Hence, the figures presenting the measured indexes together precisely, were required for comparison between indexes. In this case, unities of axes and data densities, same scales between curves, and uniform reference lines are available.

3. Results

3.1. *Time course analysis*

Figure 1 showed the measured data of single subject in full-time range of experiment. The data of other subjects were similar to this one. There were three transverse axes, which were respectively marked as *time* and *test N* in this figure, which meant the time axes had accurate movement to hold the measurements of all variables together. "Test N" denoted the group numbers in the tests. The other two time axes have coordinates referring to specific moment in the experiment such as "150, 390 and 510", in the upward side and under-part of the figure. There are four vertical axes in the figure, which are RER and HR, muscle oxygen indexes (HbO_2, Hb and BV), breathe indexes (VO_2 and VCO_2), respectively.

There are three types of reference lines as explained below.

(1) Nine vertical reference lines, which were established in the specific moment from time axes, and separated the figure into several parts of excesses and rest accurately. Table 1 showed the information for all subjects.
(2) Four vertical reference lines, which were established in the specific points of RER transforming from the decreasing phase to the increasing phase, and marked the specific moment of RER

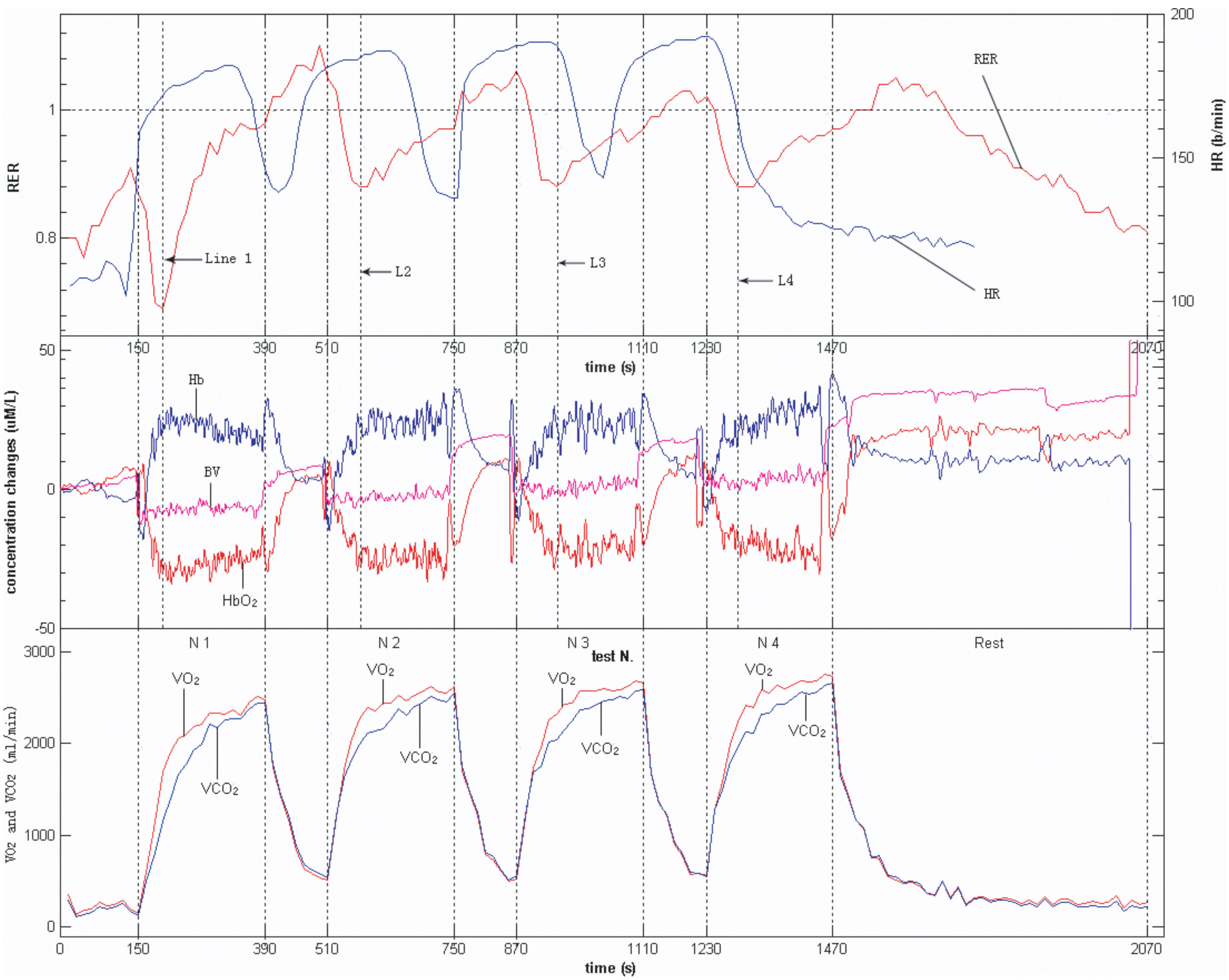

Fig. 1. Distributions of RER, HbO_2, VO_2 and VCO_2 based on time.

Table 1. Names and meanings of reference lines related in (1).

Serial numbers	Time (Sec)	Meanings	Names
1	150	starting point of group 1	L150
2	390	ending point of group 1	L390
3	510	starting point of group 2	L510
4	750	ending point of group 2	L750
5	870	starting point of group 3	L870
6	1110	ending point of group 3	L1110
7	1230	starting point of group 4	L1230
8	1470	ending point of group 4	L1470
9	2070	ending point of 10-min rest	L2070

transforming. They were named as L1, L2, L3 and L4.

(3) One transverse reference line, which was established in the co-ordinates "1" of RER axis, and offered convenience to position the respiratory quotient inflexion point (RQIP).

3.2. *Correlations between HbO_2 and RER during the early phase of exercises*

Variation tendency of HbO_2 was decreasing during the whole exercise; however, the decreasing speed is highly correlated with RER. Four vertical reference lines, as described in point (2) above, marked the specific moment of RER transforming. The remarkable high-speed decreasing of HbO_2 during the periods of RER decreasing (L150∼L1, L510∼L2, L870∼L3, L1230∼L4) was observed, which had been validated by regression analysis. On the contrary, a stable tendency of HbO_2 appears in the periods of RER increasing (L1∼L390, L2∼L750, L3∼L1110, L4∼L1470), which had also been validated by regression analysis. Quantifications on the decreasing speed of HbO_2 had provided the regression coefficients, which are listed in Table 2.

4. Discussions

4.1. *Energy metabolism during the early phase of exercises*

The first step. Phosphate system, which contains triphosadenine (ATP) and phosphagen (CP), was the primary sources of energy. ATP and CP stockpiled in skeletal muscles were used to provide energy in the early phase of exercises; however, reserves of ATP and CP were limited and they would be exhausted in a few seconds.

Table 2. Regression analysis of HbO_2 decreasing speed.

Serial numbers	RER	Reference lines	Coefficients	P
1	↓	L150∼L1	−1.249	$P = 0.000$
2	↑	L1∼L390	−0.079	$P = 0.032$
3	↓	L510∼L2	−0.814	$P = 0.000$
4	↑	L2∼L750	−0.109	$P = 0.000$
5	↓	L870∼L3	−0.711	$P = 0.000$
6	↑	L3∼L1110	−0.075	$P = 0.018$
7	↓	L1230∼L4	−0.785	$P = 0.000$
8	↑	L4∼L1470	−0.058	$P = 0.047$

The second step. Glycolysis, instead of phosphate, became the main sources of energy.[8] Compared with tricarboxylic acid cycle, glycolysis is less efficient but more rapid. In the early phase of exercises, requirement of ATP increases with exercise intensity. The speed of energy releasing of tricarboxylic acid cycle was not rapid enough, so organism needed a speedy energy releasing. In this period there was glycolysis during exercise, regardless of whether VO_2 was sufficient or not. One of the products of glycolysis was pyruvic acid, which could penetrate into the mitochondria for tricarboxylic acid cycle when O_2 was sufficient. However, the conversion of pyruvic acid to LA was catalyzed by lactate dehydrogenase, which was reversible. From there LA was accumulated.[9]

The third step. Redundant glycolysis would cease when enough energy was released from tricarboxylic acid cycle. It would be the main sources of energy in this period.

The second step was a mutative process. Glycolysis was intense in the case that there was not enough energy released from tricarboxylic acid cycle. Glycolysis would be less intense until glycolysis became ahead of tricarboxylic acid cycle, and then the third step began and LA stopped accumulating.

4.2. *Feature of RER during the early phase of exercises*

There was a decreasing tendency during the early phase of exercises. When the athlete started the sport, there were rapid responses from respiratory system and cardiovascular system, especially the respiratory system. VO_2 increased immediately, however, superfluous glycolysis, which did not consume O_2, still existed in organisms during the second step of energy cycle. In other words, O_2 was still being consumed in the mitochondria by tricarboxylic acid cycle. Therefore, not much CO_2 was released. So VO_2 increased faster than VCO_2,[11] and RER decreased.

4.3. *Feature of HbO_2 during the early phase of exercises*

HbO_2 decreased rapidly during the early phase of exercises. The concentration of HbO_2 in blood was determined by affinity between hemoglobin and O_2, which was proportional to the partial pressure of oxygen (PO_2).

The affinity was also influenced by factors such as pH value of blood, partial pressure of carbon dioxide (PCO_2) and temperature of blood.

The accumulation of a significant amount of lactate in the blood facilitated the release of oxygen from HbO_2 via the Bohr effect. This physiological mechanism is significant for supplying O_2 to skeletal muscles during sports in humans.[12–15]

4.4. *Correlations between HbO_2 and RER during the early phase of exercises*

According to the above-mentioned analysis, the finding that RER and HbO_2 decreased simultaneously had been confirmed by regression analysis. However, there were differences between them. HbO_2 measured by NIRS reflected the metabolic changes that occur directly at the muscle site, whereas the alterations in respiratory gas exchange measurements, which theoretically was based on the metabolic changes, occurred in the muscle.

5. Conclusions

There were strong correlations between oxy-hemoglobin and respiratory exchange ratio in quadriceps muscle of the thigh during the early phase of exercises. NIRS served as a new means to evaluate an athlete's training regimen in terms of HbO_2.

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