Non-Destructive Monitoring of Oxyhemoglobin Concentration Changes in Muscle during Exercise

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Abstract. Rowing is an aerobic endurance events, the human aerobic ability and anaerobic ability are very high requirements. In this study, 10 teenage male rowers were selected as subjects, and their body shape, sports quality, biochemical indexes, maximum oxygen intake, lactic acid, fujia n, dynamometer performance and related indexes were measured. On the body shape, body function, biochemical metabolism, movement quality indexes of comprehensive evaluation, can understand the athletes' physical fitness level and characteristics, through the analysis of some physiological and biochemical indexes of athletes, the athletes were evaluated by special aerobic and anaerobic exercise capacity, comprehensive evaluation of the athletes' physical fitness, hope to provide experiment basis for training plan, and to explore the feasibility of using physiological parameter prediction rowing results.

1. Introduction

Oxygen is the foundation of all life activities. The normal physiological activities of human tissue cells depend on a continuous and sufficient supply of oxygen. Hemoglobin is the main carrier of oxygen in tissues. It consists of oxyhemoglobin (HbO₂) and reduced hemoglobin (Hb). The oxygen in tissues is basically in the form of oxyhemoglobin in the capillaries in tissues. As the aerobic metabolism of the human body changes, the percentage of oxyhemoglobin in the content of the sum of the concentrations of oxyhemoglobin and reduced hemoglobin, for example blood oxygen saturation also changes [1]. Therefore, the development of effective detection technology, by measuring the oxygenation degree of hemoglobin in tissues and blood, real-time, in vivo, continuous monitoring of oxygen metabolism and transport process in human tissues, has important significance and application prospects for life science research [2,3].

In clinical practice, the most commonly used measure of blood oxygen content is to directly extract arterial blood, determine blood pH, oxygen partial pressure and carbon dioxide partial pressure, and calculate arterial oxygen saturation[4–6]. The defect is that the blood measurement needs to be taken directly, the process is cumbersome, the reliability is poor, and the continuous monitoring cannot be performed with a certain pain. With the rapid development of science and technology, oximeters have come out on one after another. Pulse oximeters can continuously measure arterial oxygen saturation in humans without penetrating blood vessels, and are widely used in clinical practice [7,8]. The measurement principle is based on the difference in the absorption of two different wavelengths of near-infrared light by oxyhemoglobin and reduced hemoglobin, and the corresponding changes in the arterial blood volume of each pulse wave, which can change the transmission of two near-infrared
light and arterial blood[9,10]. Oxygen saturation is combined to achieve continuous, non-invasive monitoring. The application of NIRS can be traced back to the 1940 exploration of arterial oxygen saturation and tissue oxygen saturation devices. Following the advent of the ear oximeter, it requires cumbersome adjustments for each measurement and is therefore not widely used [11–13].

Research on near-infrared spectroscopy has been around for a long time. In 1977, Jobsis first reported the absorption characteristics of hemoglobin and cytochrome in specific near-infrared regions in "Science" magazine, and found that oxyhemoglobin and reduced hemoglobin have two absorption peaks at 735 nm and 850 nm, respectively, and their changes can reflect the oxygen loading of hemoglobin [14,15]. The report has attracted widespread attention in the biomedical community. Different detection methods of NIRS have been successfully used to study the changes of aerobic metabolism of active and inactive muscles in different sports for 10 years. Chance and his collaborators first used NIRS technology to study the bio-energy of human muscles in 1992 and applied it to exercise training. They monitored the supply and utilization of local muscle tissue oxygen and the quadriceps of elite rowers. The recovery of oxygenation after exercise showed that the recovery of maximal oxygenation of the quadriceps muscle was proportional to the exercise intensity, that is, the greater the exercise intensity, the longer the oxygen recovery time; the oxyhemoglobin and oxygenated myoglobin were also observed. The recovery time has a certain relationship with the blood lactate concentration. They believe that different indicators of individual oxygenation and oxygenation changes during exercise and recovery may provide a reference for the rationality of rowing exercise training load. Ding et al studied 18 excellent male athletes and 8 healthy ordinary subjects, doing 50W incremental load exercise on power bicycles to exhaustion. Studies have shown that muscle oxygen metabolism can be assessed by changes in muscle oxygen monitored by NIRS during exercise. These variables are significantly different between elite athletes and ordinary people [16,17].

However, due to the high cost of the equipment and the inconvenience of being too bulky, the research on muscle oxygen has been stuck in a few laboratory stages and it is difficult to extend to real sports training and competition venues. Moxy is a compact, portable, wireless real-time monitoring device for aerobic metabolism of muscle tissue. Measurement of oxygen saturation, oxyhemoglobin, and total hemoglobin in human skeletal muscle tissue by Near-Infrared Spectroscopy (NIRS) to assess oxygen consumption and oxygen transport capacity of target muscles The functional characteristics of the target skeletal muscle system are evaluated and used for athletes' muscle function assessment, daily training, assisted diagnosis of muscle system diseases and injuries, and work instruction in rehabilitation training [18,19].

The biggest breakthrough in training and monitoring equipment in the past is that it can perform real-time, non-invasive and continuous accurate monitoring of muscle oxygen consumption, which helps users to adjust the exercise intensity according to the muscle oxygen index. Thanks to its small size (61*44*21mm), light weight (48g), long working hours (recording time >8h), waterproof and moisture-proof, and compatibility with a variety of ANT devices, Portable muscle HbO2 monitor can help coaches and athletes marathon, The design and adjustment of exercise programs in long-distance aerobic endurance training such as cycling, swimming, and skiing are also applicable to the effect evaluation and strength monitoring of muscle oxygen consumption in strength training.

2. Materials and Methods

Through cardiovascular risk assessment, PAR-Q questionnaire and physical health testing, and recording the basic conditions of the height, weight, blood pressure, heart rate and body composition, 15 experimental volunteers were recruited. The subjects were all excellent canoeists, with the sports grade of national second-class athletes.

| Table 1. Subject characteristics. Data are expressed as Mean ± SD. |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| N               | Age (years)     | Body mass (kg)  | Height (cm)     | VO2max (mL•kg⁻¹•min⁻¹) |
| 15              | 18.9±1.7        | 63.3±5.8        | 182.5±3.6       | 48.3±3.4         |
The starting power of the exercise is 50W, incrementing 50W every 3 minutes, and continuing to exercise until exhaustion, which is shown in Figure 1. A test method for progressively increasing the load on the power bicycle is adopted. In this experiment, in order to detect changes in muscle oxygen content as a function of the progressive increase in exercise load and changes in exercise time, the quadriceps muscle with the largest volume in the human body and the main motility muscle in this movement was selected as the monitoring point of the change of muscle oxygen content. The data baseline was adjusted before the subject stepped on the bicycle, and the test was started after about 1 to 2 minutes of stabilization. All tests were performed under the supervision of a cardiologist. A portable NIR spectrometer was used in this research to measure muscle oxygenation (Moxy, U.S.A.). Incremental experiments were carried out on a bicycle ergometer (MONARK, Sweden) and monitored by a heart monitor (Polar, Finland).

3. Results

As shown in Figure 2, the relative changes in oxyhemoglobin (HbO2) content in skeletal muscle tissue were more obvious. With the increase of exercise load and the prolongation of exercise time, the content of oxyhemoglobin (HbO2) in skeletal muscle tissue decreased, and the change was more obvious between different levels of load. At the same time, we also observed that after the end of exercise, the concentration curve of oxyhemoglobin has a sharp rebound and a rising phase.

As shown in Figure 3, when the subject was exercising at a low level of load in the experiment, the increase of blood lactic acid is not obvious at the first several workload state, and when the load was gradually increased, the blood lactic acid increased significantly. The lactic acid concentration inflection point of the subject occurred between the fourth and fifth stage loads.
4. Discussion

Nowadays, sports training is in a period of great change, from experience training mode to scientific training mode. Using physiological and biochemical indicators to observe athletes’ response to sports load and scientifically monitor and adjust sports load is an important part of scientific training. Therefore, sports researchers and coaches at home and abroad attach great importance to the use of physiological and biochemical indicators to accurately and timely understand the physical function of athletes, rationally arrange and adjust training plans, avoid excessive fatigue, reduce sports injuries and maximize sports performance.

The metabolic activity of the body is closely related to the oxygen content in the blood. Changes in blood oxygen concentration can directly reflect the oxygen supply and oxygen utilization of the body, which in turn reflects the changes in metabolic activity and the strength of exercise. Therefore, continuous measurement of blood oxygen content in exercise training is very beneficial for grasping changes in metabolic status, controlling training intensity, and improving exercise performance. The oxygen required for tissue metabolism in the body during exercise is obtained from the blood. For example, within a few minutes of the initial exercise of increasing load intensity, due to muscle ischemia, oxygen supply to the oxygen-deficient muscle during deoxygenation is insufficient. Oxygen metabolism plays an important role and lactic acid production increases. In the middle and late stages of exercise, when the body reaches stable oxygen consumption, the oxygen consumption and oxygen supply of the muscle reach equilibrium, and the energy of exercise is mainly provided by aerobic metabolism. At this time, the oxygen consumption rate is substantially stable, and the oxygen content in the blood also tends to be stable. The lactic acid production in the muscle is relatively reduced during the stationary phase, and its concentration is maintained at a certain level. After exercise, the human body is in the process of recovery, the oxygen content in the blood increases, and lactic acid is gradually removed. After the exercise stopped, the blood oxygen concentration began to rise.

Although the human body stimulates the local vasodilation of the skeletal muscle and the local blood flow to increase several times under the stimulation of exercise load, the demand and consumption of blood and oxygen during the exercise of the human body will greatly increase, forming a situation in which the inability to make ends meet. With the increase of exercise load, the content of oxyhemoglobin gradually decreased, while the oxygen supply capacity increased slowly. The oxygen content in the original capillaries could not be fully maintained during exercise, resulting in the original balance of oxygen transfer and oxygen consumption being destroyed, but after a certain load, the oxyhemoglobin content in the skeletal muscle no longer decreases significantly due to the large individual differences. This phenomenon indicates that the oxygen supply and demand will reach a new dynamic balance when the exercise exceeds a certain intensity.

Figure 3. Blood lactate concentration changes during graded incremental exercise.
5. Conclusion
The results of this study confirmed that the subjects exercised under different intensity loads, and the relative changes in oxyhemoglobin content and reduced hemoglobin content in skeletal muscle tissue showed a regular change between exercise intensity, which utilized the muscle oxygen phase in skeletal muscle tissue. In the ascending load movement, with the increase of the exercise load and the prolongation of the exercise time, the blood lactate concentration gradually increases. When the exercise intensity reaches a certain load, the lactate inflection point of the blood lactate increases sharply. The intensity of exercise corresponding to this point is the threshold intensity of lactate, which reflects the transition point or turning point of the metabolic mode of the body from aerobic metabolism to anaerobic metabolism. This high correlation between changes in blood lactate concentration and changes in oxyhemoglobin content during exercise of different intensity loads introduces new test indicators for physiological evaluation of athletes and physiological evaluation of exercise training effects. A new evaluation system is established for the physiological evaluation of athletes and the biological evaluation of exercise training effects, which provides a new way for non-destructive testing methods in future sports training.

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