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Estimating Human Skeletal Muscle Oxidative and Oxygen Diffusion Capacities Using Near-Infrared Spectroscopy

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Abstract

During exercise, the culmination of the O_2 cascade is contingent upon the interaction between microvascular to intramyocyte differences and muscle O_2 diffusion capacity. Presently, there is a lack of non-invasive techniques for determining in human subjects. Utilizing near-infrared spectroscopy (NIRS) and intermittent arterial occlusions to measure the recovery rate constant (k) of muscle oxygen uptake (m), we have established its correlation with in vivo muscle oxidative capacity. We postulated that k would be constrained by under conditions of low muscle oxygenation (kLOW). We proposed two hypotheses: (i) k in optimally oxygenated muscle (kHIGH) is linked to the maximum O_2 flux within fiber bundles; and (ii) the difference (Δk) between kHIGH and kLOW is associated with capillary density (CD). In a study involving 12 participants, we employed NIRS to assess the vastus lateralis k following moderate exercise. The timing and duration of arterial occlusions were manipulated to maintain the tissue saturation index within a 10% range either below (LOW) or above (HIGH) half-maximal desaturation, which was determined during sustained arterial occlusion. The maximal O_2 flux in the phosphorylating state was determined to be 37.7 ± 10.6 pmol s^{-1} mg^{-1} (∼5.8 ml min^{-1} 100 g^{-1}), and CD ranged from 348 to 586 mm^{-2}. kHIGH surpassed kLOW (3.15 ± 0.45 vs. 1.56 ± 0.79 min^{-1}, P<0.001). While maximal O_2 flux correlated positively with kHIGH (r=0.80, P=0.002), there was no correlation with kLOW (r=–0.10, P=0.755). The range of Δk extended from –0.26 to –2.55 min^{-1}, and it exhibited a negative correlation with CD (r=–0.68, P=0.015). It is evident that solely reflects muscle oxidative capacity under conditions of optimal oxygenation. Moreover, the disparity (Δk) between well-oxygenated and poorly oxygenated muscle was found to be linked to CD, a key factor in. The assessment of muscle k and Δk through NIRS offers a non-invasive avenue for gaining insights into muscle oxidative and O_2 diffusion capacities.

Keywords: Infrared spectroscopy • Incremental exercise • Muscle oxygen

Introduction

The intricate interplay between skeletal muscle oxidative capacity and oxygen diffusion capacity is at the heart of human endurance and athletic performance. Understanding the metabolic and physiological factors that influence these capacities can provide valuable insights into optimizing training, enhancing athletic performance, and improving overall health. Near-infrared spectroscopy has emerged as a powerful tool for non-invasive assessment of these essential physiological parameters. This article delves into the fascinating realm of NIRS and its application in estimating combined skeletal muscle oxidative capacity and O_2 diffusion capacity in humans.

The crucial duo: Oxidative capacity and O_2 diffusion capacity

Skeletal muscle oxidative capacity, often referred to as aerobic capacity or mitochondrial function, is a critical determinant of an individual's ability to sustain prolonged exercise. It is the muscle's capacity to generate energy through aerobic metabolism, utilizing oxygen to break down glucose and fatty acids. Higher oxidative capacity results in improved endurance and a delay in the onset of fatigue.

Oxygen diffusion capacity, on the other hand, refers to the efficiency of oxygen transport from the lungs to the muscle tissues. It involves the exchange of oxygen between the alveoli in the lungs and the blood, as well as the subsequent transport of oxygen by red blood cells and the release of oxygen to the working muscles. Efficient oxygen diffusion is vital for maintaining optimal energy production during exercise and supporting overall muscle function.

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Description

Near-Infrared Spectroscopy (NIRS) unveiled

NIRS is a non-invasive optical technique that utilizes the principles of light absorption and scattering in the near-infrared range (typically 650-1000 nm) to measure tissue oxygenation levels. It offers real-time insights into the balance between oxygen delivery and utilization, making it a valuable tool for assessing both skeletal muscle oxidative capacity and oxygen diffusion capacity.

NIRS operates on the principle that different molecules absorb light at specific wavelengths. Hemoglobin and myoglobin, the oxygen-carrying proteins in blood and muscle tissue, have distinct absorption spectra. When illuminated with near-infrared light, these molecules change their light absorption characteristics based on their oxygenation levels. By measuring the changes in light intensity as it passes through tissue, NIRS can provide information about tissue oxygenation and metabolic activity.

Estimating skeletal muscle oxidative capacity

NIRS can estimate skeletal muscle oxidative capacity by monitoring changes in the levels of oxygenated and deoxygenated hemoglobin and myoglobin during exercise. This information offers insights into the muscle's ability to extract and utilize oxygen. Researchers can assess the rate of oxygen consumption and oxidative metabolism, allowing them to quantify an individual's aerobic capacity and predict their endurance potential.

Assessing oxygen diffusion capacity

Oxygen diffusion capacity can also be inferred from NIRS measurements by analyzing the rate at which oxygen is delivered to and extracted by the muscle tissue. By examining the oxygen dynamics during exercise, researchers can gain valuable information about the efficiency of oxygen transport from the lungs to the muscles. This insight helps in identifying factors that might limit oxygen delivery and aids in tailoring training strategies to improve overall oxygen diffusion efficiency.

Applications and implications

The integration of NIRS into exercise physiology and sports science has opened up new avenues for understanding the intricate relationship between oxidative capacity and oxygen diffusion capacity. Athletes and coaches can utilize this technology to fine-tune training programs, optimize recovery strategies, and monitor adaptations in real-time. Additionally, NIRS holds promise in clinical settings, enabling the assessment of muscle function in patients with cardiovascular and metabolic diseases [1-6].

Conclusion

Near-infrared spectroscopy has emerged as a revolutionary tool for estimating combined skeletal muscle oxidative capacity and O_2 diffusion capacity in humans. By providing non-invasive, real-time insights into muscle metabolism and oxygen dynamics, NIRS contributes to our understanding of human performance and health. As research continues to unveil the full potential of this technology, we can expect it to play an increasingly integral role in enhancing athletic prowess, optimizing training methodologies, and advancing our knowledge of human physiology.

Acknowledgement

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Conflict of Interest

None.

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