シI-3 Intracellular Oxygen Supply and Respiration in Exercising Muscle

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During exercise the ability of the working muscle in human to increase its oxygen uptake is limited by either a central or a peripheral mechanism. The central mechanism represents the systemic increase in oxygen delivery to the muscle, which includes enhanced blood flow through the capillaries. The peripheral mechanism focuses on the diffusion of oxygen from Hb to the mitochondria and the metabolic regulation of oxidative phosphorylation. Even though both models entail an O_2 gradient role, the diffusion model emphasizes the gradient from the capillary to the mitochondria, which is a driving force of O_2 transport. The observation implies that the cell can modulate its O_2 gradient and suggests that Mb facilitated diffusion, which becomes increasingly pronounced as the cellular pO_2 falls, might contribute significantly to O_2 transport to the mitochondria. The ^{1}H-NMR has presented an approach to shed light on the competing mechanisms. During plantar flexion with a constant load at a deferent repetition rate, VO_2 increases linearly with exercise intensity . The ^{31}P NMR indicates that PCr decreases to 32 %, while muscle pH decreases linearly. Muscle ATP, however, remains constant during exercise. The deoxy Mb signal decreases in proportion to increments in power output and VO_2. At the highest exercise intensity and peak VO_2, Mb is approximately 48% desaturated. The dynamics of the Mb desaturation kinetics shows that the cellular O_2 supply decreases rapidly, within 30s as VO_2 increases. The whole body VO_2 kinetics time constant is almost 4 times longer and mirrors the PCr kinetics. During recovery, the PCr recovery rate also lags the Mb resaturation rate. These findings, taken together, suggest that the O_2 gradient from Hb to the mitochondria can modulate the O_2 flux in order to meet the increased VO_2 in exercising muscle. The time scale of the Mb desaturation is rapid relative to the expected alteration in convective flow. But declining cellular pO_2 during enhanced mitochondrial respiration also suggests that availability does not limit VO_2 during exercise.

シI-4 Quantitative measurements of muscle O_2 consumption with noninvasive methods and their applications for studies in exercise physiology

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Skeletal muscle O_2 consumption is a key parameter of metabolism under various conditions. Near infrared continuous wave spectroscopy (NIRcws) was developed for measuring changes in muscle oxygenation and, in human studies, a method of nonivasive estimation for the quantitative values of muscle O_2 consumption (VO_{2NIR}) in exercise has been expected to be a useful alternative in the study of exercise physiology.

Validation of $\dot{V}O_{2NIR}$: Quantitative measurements of NIRcws were examined in our previous studies. Changes in the ratio of the decline rate of HbO_2 during arterial occlusion post exercise, as to at rest were closely related with the changes in PCr and ADP concentrations. Quantitative values of VO_{2NIR} also had a high correlation with the oxidative metabolic rates as the gold standard measured by ^{31}P-MRS.

Peak $\dot{V}O_{2NIR}$ during incremental exercise: The changes in VO_{2NIR} in relation to cytosolic pH and high-energy phosphates of human skeletal muscle during incremental handgrip exercise were examined by both NIRcws and ^{31}P-MRS. Exercise load was increased by 5% of MVC every minute from 0% MVC until exhaustion. The exercise period was 48 sec at each load and VO_{2NIR} was measured during 7 sec following exercise by NIRcws using the partial arterial occlusion method. The VO_{2NIR} at exhuastion were not the peak values during handgrip exercise. The negative effect of lower cytosolic pH on the VO_{2NIR} at exhuastion could overcome the positive effect of lower PCr.

Effects of muscle oxygenation level on $\dot{V}O_{2NIR}$: The VO_{2NIR} at the different oxygenation levels (m-O_2) were examined at 20% MVC during 20 sec of isometric exercises. The HbO_2 level at rest was determined as 100% and the lowest level as 0% during 6 to 7 min of arterial occlusion. The VO_{2NIR} significantly decreased at the 60% of m-O_2 compared with those at 100% of m-O_2. The lower the m-O_2, the lager the decrease in VO_{2NIR}. Under conditions in which VO_{2NIR} measured during isometric exercise with arterial occlusion, the decrease in O_2 partial pressure could be one of the limitations of VO_{2NIR} during exercise.