MUSCLE OXYGENATION HETEROGENEITY IN A SINGLE MUSCLE AT REST AND DURING BICYCLE EXERCISE

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Abstract

We evaluated regional differences of muscle O₂ dynamics between distal and proximal sites in the vastus lateralis (VL) muscle using near infrared spatial resolved spectroscopy (NIR_{SRS}). Forty-one male subjects performed a 30 W ramp incremental bicycle exercise test until exhaustion. The NIR_{SRS} probes were attached on each distal and proximal site in the VL. The pulmonary O₂ uptake and heart rate were monitored continuously during the experiment. The TOI at rest was significantly higher in proximal than distal sites (65.0 ± 5.2 vs. $69.7 \pm 4.6\%$, $p < 0.001$). The TOI at exhaustion was also significantly higher in proximal than distal sites (39.5 ± 6.7 vs. $47.5 \pm 7.6\%$, $p < 0.001$). Moreover, a significant correlation was found between $\dot{V}O_{2\max}$ and the TOI at exhaustion in each proximal and distal site in the VL. Half time reoxygenation, the time to reach a value of half-maximal recovery, was significantly slower in distal sites than proximal sites (27.1 ± 5.6 vs. 25.0 ± 6.1 sec, $p < 0.01$). In conclusion, lower muscle oxygenation at exhaustion in higher $\dot{V}O_{2\max}$ may be due to enhanced O₂ extraction in high oxidative capacity muscle. In addition, slower reoxygenation and lower muscle deoxygenation at the distal site in the VL may be explained by differences in O₂ supply and/or muscle fiber composition between distal and proximal sites.

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Introduction

Muscle perfusion is a key parameter of aerobic metabolism under various conditions and has been a popular research subject for many years. It is clear that muscle oxygen consumption (muscle $\dot{V}O_2$) increases linearly in relation to muscle perfusion^{1,2}). Moreover, it has been also shown that muscle perfusion and muscle $\dot{V}O_2$ are affected by differences in muscle fiber composition, microvascular structure and motor unit recruitment pattern^{3,4}). Recently, heterogeneity of muscle deoxygenation during exercise in humans has been evaluated using positron emission tomography (PET)⁵). However, the device only produces information after exercise or during

static exercise because of moving artifacts. Therefore, it is essentially impossible to monitor heterogeneity of muscle deoxygenation during dynamic whole body exercise such as bicycle exercise using PET. Near-infrared continuous wave spectroscopy (NIR_{cws}) has been widely applied to the evaluation of muscle deoxygenation during bicycle exercise^{6,7}). More recently, we have evaluated heterogeneity of muscle O₂ dynamics during bicycle exercise using multi-channel NIR_{cws} system and found that muscle deoxygenation in a single muscle was more homogeneous at higher workloads⁸). However, the previous study could not evaluate the regional differences in muscle deoxygenation at rest because NIR_{cws} only can measure changing values from the

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baseline. In contrast, near-infrared spatially resolved spectroscopy (NIRS_{SRS}) can measure tissue oxygenation index (TOI) which allows for regional differences in muscle deoxygenation at rest and during exercise⁹). Therefore, the purpose of this study was to evaluate regional differences of muscle O₂ dynamics between distal and proximal sites in the vastus lateralis (VL) muscle at rest and during bicycle exercise using NIRS_{SRS} device.

Methods

Fifty-one male subjects participated in this study. All subjects were college students, and almost all of the subjects were trained athletes (forty-one competitive college football players, four competitive college triathletes, one pro-boxer, one competitive marathon runner, and four subjects involved in various recreational activities). All subjects were briefed about the experimental protocol and written informed consent was obtained before the test.

The subjects performed a 30 W ramp incremental bicycle exercise test until exhaustion. During each test, a pedal frequency of 60 rpm was maintained by keeping time with a metronome. The tissue oxygenation index (TOI) in the VL was monitored using NIRS_{SRS} system. The TOI is derived from the relative

absorption coefficients obtained from the slope of light attenuation at four wavelengths over a distance measured at three focal points from the light emission. The relative absorption coefficients are converted to relative concentrations of oxygenated and deoxygenated-Hb. Therefore, this device can essentially calculate tissue oxygen saturation called TOI. The reliability of the TOI measured by NIRS_{SRS} has been evaluated in vivo⁹).

The NIRS_{SRS} probes were attached on each distal and proximal site in the left VL muscle. One of the probes was attached at a point one-third (1/3) from the patella to the greater trochanter as the distal site, and the other probe was attached at a point two-third (2/3) as the proximal site. The pulmonary O₂ uptake and heart rate were monitored continuously during the experiment. Blood samples were taken for blood lactate concentration measurement at 150, 210, 270, 330 W, and exhaustion. The changes in recorded parameters during the exercise test were analyzed by one-way ANOVA for repeated measurements. Following a significant *F* test, pair-wise differences were identified using Tukey's honestly significant difference (HSD) post hoc procedure. When appropriate, significant differences were also identified using Student's paired *t* tests. The significant

Fig. 1. Muscle deoxygenation at distal and proximal sites before and during bicycle exercise.

level was set at $P < 0.05$.

Results

The TOI at rest was significantly higher in proximal than distal sites (distal; 69.2 ± 4.5 vs. proximal; $64.3 \pm 5.3\%$, $p < 0.001$). In addition, TOI was more deoxygenated at the distal site than the proximal site throughout the exercise, and the TOI at exhaustion was also significantly higher in proximal than distal sites (distal; 47.7 ± 7.4 vs. proximal; $39.7 \pm 6.9\%$, $p < 0.001$) [Fig. 1]. [La] started

to accumulate around 600 sec and increased further at higher workloads. The point at which La started to accumulate (≈ 600 sec), was close to the point at which muscle deoxygenation at distal site was leveling off.

There was a significantly negative correlation between $\dot{V}O_{2\max}$ and TOI at exhaustion at each measurement site (Fig. 2 A, Fig. 2 B). Half time reoxygenation, the time to reach a value of half-maximal recovery, was significantly slower in distal sites than proximal sites (distal; 27.1 ± 5.6 vs. proximal;

A (Distal)

B (Proximal)

Fig. 2. Relationship between $\dot{V}O_{2\max}$ and TOI at exhaustion at distal site (A) and right proximal site (B).

25.0±6.1 sec, $p < 0.01$)

Discussion

TOI was significantly lower at the distal site than the proximal site at rest and throughout the bicycle exercise. These results may be explained by differences in muscle blood flow and/or muscle oxygen consumption, muscle activity, and muscle fiber composition in each measurement site.

In this study, the point at which La started to accumulate, was close to the point at which muscle deoxygenation at distal site was leveling off. And this result is in contrast to Grassi et al¹⁰ reported that muscle deoxygenation was accelerated after LT point due to bore effects. The reason why muscle deoxygenation was leveling off around LT point may be due to recruitment of synergetic muscles of the other quadriceps and/or triceps surae muscles.

There was a significantly negative correlation between these parameters at each measurement site (Fig. 2) These result suggest that oxygen extraction may be enhanced in high oxidative capacity muscle at each measurement site . In addition, slower reoxygenation and lower muscle deoxygenation at the distal site in the VL may be explained by differences in O₂ supply and/or muscle fiber composition between distal and proximal sites.

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