Chapter 22
Aging Affects Spatial Distribution of Leg Muscle Oxygen Saturation During Ramp Cycling Exercise

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Abstract We compared muscle oxygen saturation (SmO_2) responses in several leg muscles and within a single muscle during ramp cycling exercise between elderly men ($n = 8$; age, 65 ± 3 years; ELD) and young men ($n = 10$; age, 23 ± 3 years; YNG). SmO_2 was monitored at the distal site of the vastus lateralis (VLd), proximal site of the vastus lateralis (VLp), rectus femoris (RF), vastus medialis (VM), biceps femoris (BF), gastrocnemius lateralis (GL), gastrocnemius medialis (GM), and tibialis anterior (TA) by near-infrared spatial resolved spectroscopy. During submaximal exercise, significantly lower SmO_2 at a given absolute work rate was observed in VLd, RF, BF, GL, and TA but not in VLp, VM, and GM in ELD than in YNG. In contrast, at all measurement sites, SmO_2 at peak exercise was not significantly different between groups. These results indicate that the effects of aging on SmO_2 responses are heterogeneous between leg muscles and also within a single muscle. The lower SmO_2 in older men may have been caused by reduced muscle blood flow or altered blood flow distribution.

22.1 Introduction

Near-infrared spectroscopy (NIRS) has been widely used in measuring muscle oxygenation. Muscle oxygen saturation (SmO_2), which is measured by NIRS, is an indicator of the balance between local O_2 delivery and O_2 consumption. SmO_2 in the

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vastus lateralis (VL) muscle has been founded to decrease during incremental cycling [1], and the decline of SmO_2 was likely attributed to higher O_2 consumption than O_2 delivery.

Aging may reduce O_2 delivery to activating muscle during rest and exercise. A previous study reported that muscle deoxygenation in VL measured by NIRS was enhanced in older compared to younger subjects during cycling exercise due to reduced oxygen supply to activating muscle [2]. However, it has been reported that the O_2 balance is distributed heterogeneously between leg muscles and also within a single skeletal muscle [1, 3]. As aging also alters distribution of blood flow between muscles [4], influence of aging on SmO_2 responses are heterogeneous between muscles and within a single muscle. The purpose of this study was to compare SmO_2 responses between elderly and young subjects in several leg muscles and within a single muscle during cycling exercise.

22.2 Methods

22.2.1 Subjects

Eight elderly men (ELD; age, 65 ± 3 years; height, 166.4 ± 5.4 cm; weight 66.4 ± 5.0 kg; mean ± SD) and ten young men (YNG; age, 23 ± 3 years; height, 174.1 ± 7.3 cm; weight, 66.0 ± 7.0 kg; mean ± SD) participated in the study, which was approved by the Tokyo Medical University Local Research Ethics Committee, Japan. In ELD, one subject was taking a calcium channel blocker, one subject was taking an angiotensin-converting enzyme inhibitor, and one subject was taking a statin and angiotensin II receptor antagonist. All volunteers were informed of the purpose and nature of the study, after which their written informed consent was given.

22.2.2 Experimental Design

The subjects performed 15 W/min (ELD) or 20 W/min (ELD and YNG) ramp bicycle exercise (after a 3-min warm up at 0 or 10 W) until exhaustion (Strength Ergo 8, Fukuda-Denshi, Tokyo, Japan). Pulmonary O_2 uptake (VO_2) was monitored continuously during the experiments to determine peak VO_2 with an online metabolic system (AE300S, Minato Medical Science, Osaka, Japan). Pedal frequency of 50 rpm (for ELD) or 60 rpm (for YNG) was maintained by keeping time with a metronome.

Muscle O_2 saturation (SmO_2) was monitored at the distal site of the VL (VLd), proximal site of the VL (VLp), rectus femoris (RF), vastus medialis (VM), biceps femoris (BF), gastrocnemius lateralis (GL), gastrocnemius medialis (GM), and tibialis anterior (TA) in the left leg by multichannel near-infrared spatial resolved

spectroscopy (NIR_{SRS}). VLd was defined as 9–13 cm above the patella (30 % of the length between the patella and the greater trochanter). VLp was defined at a proximal point of 30 % of the length between the patella and the greater trochanter, from the VLd muscle. The SmO_2 values were defined as the SmO_2 averaged over the last 10 s at rest, every 20 W, and exhaustion.

We used a two wavelength (770 and 830 nm) light-emitting diode NIR_{SRS} (Astem Co., Japan). The probe consisted of one light source and two photodiode detectors, and the optode distances were 20 and 30 mm, respectively. In this study, we measured fat layer thickness at each measurement site in the muscles to correct for the light-scattering effects on SmO_2 [5] using an ultrasound device (LogiQ3, GE-Yokokawa Medical Systems, Japan) by placing an ultrasound probe at the same sites as the NIR_{SRS} probes had been placed. Even though an upper limit of fat layer thickness was designated as 1 cm to correct for the light-scattering effects in this study, fat layer thickness was within ~1 cm at each measurement site in all subjects.

22.2.3 Statistics

All data are given as means ± standard deviation (SD). Differences in SmO_2 during rest and peak exercise were compared between groups using unpaired *t* tests. To compare changes in SmO_2 during submaximal exercise between groups, a two-way repeated measures analysis of variance was used with age and exercise intensity as factors. Where appropriate, the Bonferroni post hoc test was performed to determine specific significant differences. Because a subject in ELD could not exercise more than 125 W, repeated measures between groups were limited to 20, 40, 60, 80, 100, and 120 W. For all statistical analyses, significance was accepted at $p < 0.05$.

22.3 Results

The resting SmO_2 in VLd, BF, GL, and TA was significantly lower in ELD than YNG ($p < 0.05$), although it was not significantly different between groups at the other measurement sites (VLp, RF, VM, BF, and GM). There was a significant age × exercise intensity interaction for change in SmO_2 at RF ($p < 0.05$), but not at the other measurement sites. Significantly lower SmO_2 at a given absolute work rate was observed in VLd, RF, BF, GL, and TA but not in VLp, VM, and GM. Consequently, there was a significant age × exercise intensity interaction for change in SmO_2 at mean SmO_2 of whole leg muscles (VLd, RF, VM, BF, GL, GM, and TA) ($p < 0.05$), and mean SmO_2 was lower in ELD than in YNG during submaximal exercise ($p < 0.05$) (Fig. 22.1). In contrast, at all measurement sites, SmO_2 at peak exercise was not significantly different between ELD and YNG. Peak VO_2 (24.4 ± 1.5 vs. 46.4 ± 7.4 mL/kg/min, $p < 0.05$) and peak workloads (135 ± 8 vs. 250 ± 30 W, $p < 0.05$) were significantly lower in ELD than in YNG.

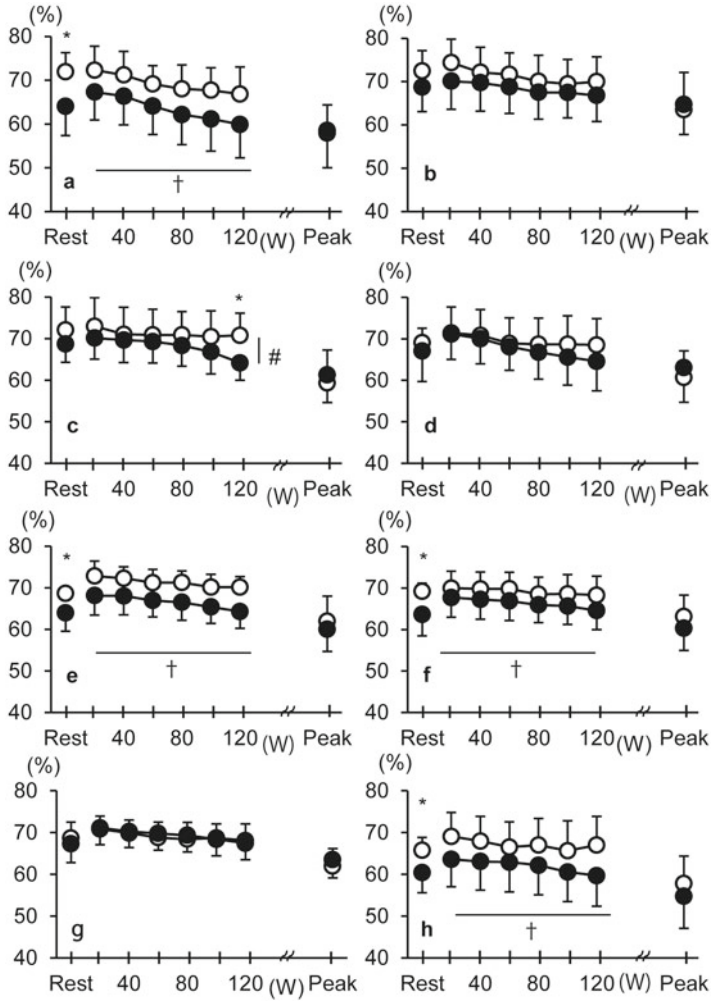

Fig. 22.1 SmO_2 responses in VLd (**a**) VLp (**b**), RF (**c**), VM (**d**), BF (**e**), GL (**f**), GM (**g**), and TA (**h**) muscles during ramp cycling exercise. The *solid circles* show SmO_2 in ELD, and the *open circles* show SmO_2 in YNG. There was a significant difference between ELD and YNG (*, $p<0.05$). There was a significant age×exercise intensity interaction (#, $p<0.05$). There was a main effect of age (†, $p<0.05$)

22.4 Discussion

The results of the present study provided two major findings. First, the SmO_2 responses during rest and submaximal exercise were different between YNG and ELD in some muscles and some parts of muscles. Second, SmO_2 at peak exercise was not affected by aging at any measurement sites. These results suggest that blood

flow and metabolic demands are heterogeneous between muscles and also within a single muscle in ELD as well as YNG, and the spatial distribution of leg SmO_2 during submaximal exercise is affected by aging.

The influences of aging on SmO_2 responses were considerably different between muscles during submaximal cycling exercise. Previous studies demonstrated that aging blunts the vasodilation responses in skeletal muscle arterioles and the age-related impairment differs between skeletal muscles [6]. Reduction in blood flow with aging may cause a compensatory increase in O_2 extraction in exercising leg muscles [7]. Therefore, the influence of aging on regional differences in SmO_2 responses may be explained by regional differences in vascular responses. Another possible reason for regional differences in effects of aging on SmO_2 response was differences in the action of the muscles. For example, SmO_2 response in RF, which is one of the knee extensor/hip flexor muscles, seemed to be decreased during relatively high exercise intensity, although it was relatively maintained until around 60 % of peak exercise [8]. Additionally, muscle perfusion and muscle O_2 consumption were presumably affected by differences in muscle fiber composition [9]. In fact, muscle fiber composition was heterogeneous between leg muscles [10] and also within a single muscle [11] in young subjects. Moreover, reduction in muscle fiber area occurred in glycolytic fibers, but not in oxidative muscle fibers with aging [12]. Musch et al. reported that reductions in blood flow mainly occurred in oxidative muscles in older rats during submaximal exercise [4]. Hence, we can speculate that the lower SmO_2 in elderly subjects can be attributed to reduced muscle blood flow or altered blood flow distribution, secondary to attenuation of vasodilation responses and/or alteration of muscle fiber composition. However, further research is needed to clarify the mechanism of regional differences in effects of aging on SmO_2 responses.

Interestingly, peak SmO_2 was not different in any muscles in the present study. In contrast, Costes et al. reported that SmO_2 at peak exercise was lower in older subjects in VL muscle [2]. The disparity was mainly caused by methods of normalizing NIRS signals. In a previous study [2], a cuff ischemia method was applied to normalize the NIRS signal to the maximal oxygenated value and the maximal deoxygenated value. Thus, absolute SmO_2 values at rest and peak exercise cannot be measured by cuff ischemia methods, in contrast to methods of correction of fat layer thickness effects. From our findings, we presume that O_2 extraction in skeletal muscle may be one of the factors in limiting exercise, regardless of age.

In conclusion, the influences of aging on SmO_2 responses are heterogeneous between leg muscles and also within a single muscle. The lower SmO_2 in elderly men may have been caused by reduced muscle blood flow or altered blood flow distribution. Furthermore, regardless of aging, oxygen extraction in skeletal muscle may be one of the factors in limiting peak VO_2, because SmO_2 at peak exercise is similar between ELD and YNG.

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