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Influence of body position on muscle deoxy[Hb + Mb] during ramp cycle exercise

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ABSTRACT

We used near-infrared spectroscopy (NIRS) to test the hypothesis that body position alters the sigmoidal response profile of muscle fractional O_2 extraction (estimated using deoxy[Hb + Mb]) during incremental cycle exercise. Seven male subjects (mean ± SD age 32 ± 13 years) completed a ramp incremental cycling test to exhaustion (30 W/min) in both the supine and upright body positions. The sigmoidal (as opposed to hyperbolic) model that provided the better fit to deoxy[Hb + Mb] data during upright cycling was also present for the supine response; however, the slope of the sigmoid was increased (upright: 0.052 ± 0.012 *vs.* supine: 0.090 ± 0.036% · $\%P_{peak}^{-1}$; $P < 0.05$) and a plateau occurred at a lower work rate (upright: 83 ± 8 *vs.* supine: 68 ± 19%P_{peak}^{-1}; $P < 0.05$) during supine exercise. These changes occurred in the absence of a leftward shift of the sigmoid. We also found a significantly greater $\Delta\dot{V}_{O_2}/\Delta W$ slope above compared to below gas exchange threshold (GET) for both conditions (upright: 9.8 ± 0.5 *vs.* 8.2 ± 0.9; supine: 10.7 ± 0.9 *vs.* 8.0 ± 0.8) and for supine compared to upright cycling above GET. These findings suggest that the supine posture affects O_2 extraction and $\dot{V}_{O_2}$ kinetics to a greater extent as work rate progresses during ramp incremental exercise.

1. Introduction

During steady state exercise, muscle blood flow ($\dot{Q}_m$) increases in proportion to muscle oxygen consumption ($\dot{V}_{O_2m}$) with a positive intercept on the *y* (blood flow) axis that is fiber-type dependent (Ferreira et al., 2006). According to the Fick principle ($\dot{V}_{O_2m} = \dot{Q}m \cdot (Ca - Cv)_{O_2}$), this relationship mandates a hyperbolic increase in fractional O_2 extraction with increasing $\dot{V}_{O_2m}$ and, by extension, work rate. However, it has recently been shown using near-infrared spectroscopy (NIRS) that the response profile of deoxygenated hemoglobin/myoglobin (deoxy[Hb + Mb]), a surrogate for microvascular O_2 extraction (DeLorey et al., 2003; Grassi et al., 2003; Ferreira et al., 2005), is better described by a sigmoidal (S-shaped) model during incremental exercise (Ferreira et al., 2007; Boone et al., 2009, 2010). This is suggestive of changes in the $\dot{Q}$m-to-$\dot{V}_{O_{2m}}$ relationship as incremental exercise proceeds.

Fig. 1 illustrates a sigmoidal deoxy[Hb + Mb]/work rate curve and, specifically, three distinct regions that such a profile implies. Assuming a linear increase in $\dot{V}_{O_2}$ with work rate during incremental exercise (but see Section 4), the blunted deoxy[Hb + Mb] rise in the initial region has been interpreted as evidence that $\dot{Q}_m$ increases faster than $\dot{V}_{O_2m}$ during the early minutes of incremental exercise (Ferreira et al., 2007, but see Boone et al., 2010). Conversely, the slope region is characterized by a markedly steeper response, which indicates greater reliance on fractional O_2 extraction as higher work rates are reached. Finally, in most subjects, a plateau occurs, which suggests an inability for O_2 extraction to increase further and implies a linear $\dot{Q}m - \dot{V}_{O_2m}$ relationship until the point of exhaustion (Ferreira et al., 2007).

A number of mechanism(s) that potentially underpin the sigmoidal deoxy[Hb + Mb] response during incremental exercise have been proposed (see Ferreira et al., 2007). Boone et al. (2010) recently found a similar response during tests that involved incremental three-minute step transitions, which suggests that the profile is not unique to the non-steady-state conditions that characterize continuous ramp exercise. This implicates factor(s) unrelated to changes in $\dot{Q}_m$ kinetics *per se* (e.g., Stringer et al., 2005; Ferreira et al., 2007) as being responsible for the sigmoidal deoxy[Hb + Mb] response to incremental exercise. The authors hypothesized that the sequential recruitment of muscle fibers from predominantly type I to a mixed type I/type II pool with increasing work rate might be responsible for the profile (Boone et al., 2010). There is evidence in both isolated rat preparations and in human muscle during exercise to suggest that fibers positioned higher in the recruitment hierarchy demonstrate greater reliance on fractional O_2 extraction to attain a given rate of oxidative metabolism (Behnke et al., 2003; McDonough et al., 2005; Ferreira et al., 2006; DiMenna et al., 2010).

Ferreira et al. (2007) developed computer simulations to assess the sigmoidal deoxy[Hb + Mb] response and advanced a model whereby the slope and plateau regions provide information that could be useful for assessing vascular function and detecting

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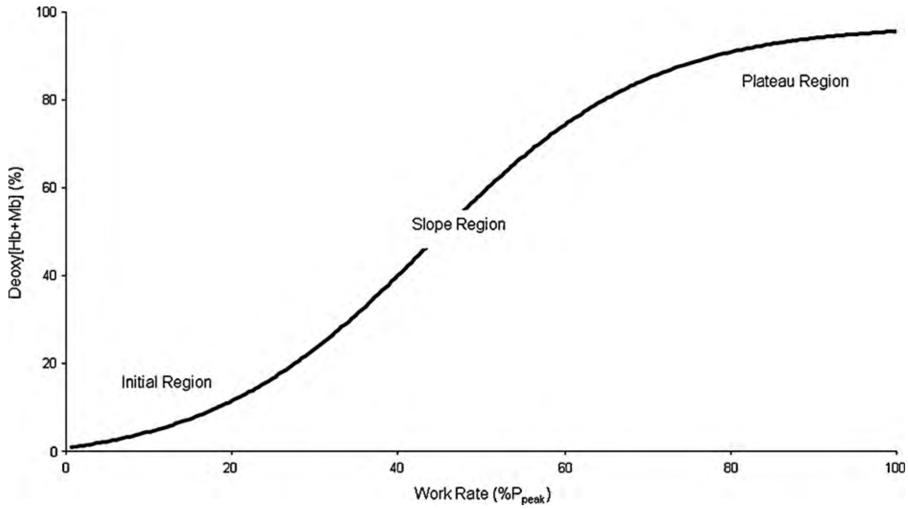

Fig. 1. Schematic representation of the deoxy[Hb + Mb] profile that has been observed as a function of work rate during upright incremental cycle exercise. The fact that a sigmoidal (S-shaped) model typically provides the better fit implies three distinct response regions. The initial region involves a blunted deoxy[Hb + Mb] response, whereas the slope region indicates greater reliance on fractional O_2 extraction per work rate increment. Finally, the plateau region reflects a linear $\dot{Q}_m$-to-$\dot{V}_{O_2m}$ rise that is likely required when fractional O_2 extraction can no longer further increase.

early stages of dysfunction during routine clinical exercise testing. Specifically, they suggested that disease-related changes in microvascular function might shift the sigmoid to the left whereas exercise training and pharmacological treatment that improves vascular function might shift the sigmoid to the right. In support of this contention, Boone et al. (2009) found a rightward shift of the deoxy[Hb + Mb] response in trained cyclists compared to physically active students. However, to the best of our knowledge, no research has been conducted to assess perturbations that might be expected to shift the sigmoid leftward.

During supine exercise where the active musculature is at or above heart level, the gravitational assist to muscle blood flow is absent and muscle perfusion pressure is reduced. Consequent to these changes, MacDonald et al. (1998) found a 60% slower time course for the adaptation of leg blood flow during supine compared to upright knee extension exercise and Jones et al. (2006) found faster deoxy[Hb + Mb] kinetics suggesting slowed tissue oxygenation during supine compared to upright cycling. These data suggest that the supine cycling model could potentially provide useful insight into alterations in muscle deoxy[Hb + Mb] kinetics that might mimic changes with vascular dysfunction. We have recently shown during light-to-moderate-intensity constant-load cycling performed in the supine position, that the NIRS-derived $\Delta[HHb]/\Delta\dot{V}_{O_2}$ (an index of the fractional O_2 extraction that is required to support a given $\dot{V}_{O_2}$ increment) was increased, but the time course of the $\dot{V}_{O_2}$ adaptation (primary time constant and time delay; τ_p and TD_p, respectively) was unchanged (DiMenna et al., 2010). Conversely, for moderate-to-severe transitions that would involve a greater proportional contribution from higher-order fibers (Wilkerson and Jones, 2006, 2007; DiMenna et al., 2008, 2009), $\Delta[HHb]/\Delta\dot{V}_{O_2}$ was unchanged and $\dot{V}_{O_2}$ τ_p was significantly lengthened (DiMenna et al., 2010). This implies fiber-type-specific sensitivity when the adaptation of $\dot{Q}_m$ is slowed and suggests that the supine cycling model could be useful for exploring non-linear aspects of the deoxy[Hb + Mb]-to-$\dot{V}_{O_2m}$ relationship during incremental exercise.

The purpose of the present study was to investigate the influence of body posture on the deoxy[Hb + Mb]/work rate (deoxy[Hb + Mb]/W) and $\dot{V}_{O_2}$/work rate ($\dot{V}_{O_2}/W$) profiles during ramp incremental exercise. We hypothesized that, in the supine compared to the upright position, the sigmoidal profile of deoxy[Hb + Mb] would be characterized by a greater slope and an earlier emergence of the plateau region, consistent with expected changes in muscle fractional O_2 extraction to compensate for a slower adaptation of $\dot{Q}_m$ under these circumstances (Ferreira et al., 2007).

2. Methods

2.1. Subjects

Seven male subjects (mean ± SD age 32 ± 13 years, stature 1.80 ± 0.05 m, mass 79.6 ± 7.0 kg) that displayed a sigmoidal profile of deoxy[Hb + Mb] during upright ramp cycle exercise were assessed for this investigation. All subjects volunteered and gave written informed consent to participate in the study, which had been approved by the University of Exeter Research Ethics Committee. The subjects were all recreationally active and were familiar with the experimental procedures used in the present study. On test days, subjects were instructed to report to the laboratory in a rested state, having completed no strenuous exercise within the previous 24 h, and having abstained from food, alcohol and caffeine for the preceding 3 h.

2.2. Experimental overview

All testing was completed in an air-conditioned laboratory at a temperature of 20–22 °C. The subjects visited the laboratory on two occasions over a 5-day period to perform exercise tests on an electronically braked cycle ergometer (Lode Excalibur Sport, Groningen, the Netherlands). Testing was conducted at the same time of day (±2 h) for each subject and laboratory visits were separated by at least 48 h. On each of these visits, the subjects completed a ramp incremental exercise test for determination of peak $\dot{V}_{O_2}$ ($\dot{V}_{O_2peak}$), peak power (P_{peak}) and gas exchange threshold (GET). The deoxy[Hb + Mb]/W and $\dot{V}_{O_2}/W$ relationships during incremental exercise were also determined from these tests. One test was performed in the upright position, the other with the subject lying supine, and test order was alternated between subjects. The supine condition was created by bracing the front of the ergometer against the wall with the rear of the ergometer supported on a horizontal structure specifically constructed for this purpose. Owing to this configuration, the angle formed between the front of the ergometer and the floor was 32 degrees and the crank shaft was positioned