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Discrepancy between femoral and capillary blood flow kinetics during knee extension exercise

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ABSTRACT

Capillary blood flow (Q_{CAP}) kinetics have previously been shown to be significantly slower than femoral artery (Q_{FA}) kinetics following the onset of dynamic knee extension exercise. If the increase in Q_{CAP} does not follow a similar time course to Q_{FA}, then a substantial proportion of the available blood flow is not distributed to the working muscle. One possible explanation for this discrepancy is that blood flow also increases to the nonworking lower leg muscles. Therefore, the present study aimed to determine if a reduction in lower limb blood flow, via arterial occlusion below the knee, alters the kinetics of Q_{FA} and Q_{CAP} during knee extension exercise, and thus provide insight into the potential mechanisms controlling the rapid increase in Q_{FA}. Subjects performed a ramp max test to determine the work rate at which gas exchange threshold (GET) occurred. At least four constant work rate trials with and without below-knee occlusion were conducted at work rates eliciting ~80% GET. Pulmonary gas exchange, near-infrared spectroscopy and Q_{FA} measurements were taken continuously during each exercise bout. Muscle oxygen uptake (VO_2m) and deoxy[hemoglobin + myoglobin] were used to estimate Q_{CAP}. There was no significant difference between the uncuffed and cuffed conditions in any response ($P > 0.05$). The mean response times (MRT) of Q_{FA} were 18.7 ± 14.2 s (uncuffed) and 24.6 ± 14.9 s (cuffed). Q_{CAP} MRTs were 51.8 ± 23.4 s (uncuffed) and 56.7 ± 23.2 s (cuffed), which were not significantly different from the time constants (τ) of VO_2m (39.7 ± 23.2 s (uncuffed) and 46.3 ± 24.1 s (cuffed). However, the MRT of Q_{FA} was significantly faster ($P < 0.05$) than the MRT of Q_{CAP} and τVO_2m. τVO_2m and MRT Q_{CAP} were significantly correlated and estimated Q_{CAP} kinetics tracked VO_2m following exercise onset. Cuffing below the knee did not significantly change the kinetics of Q_{FA}, Q_{CAP} or VO_2m, although an effect size of 1.02 suggested that a significant effect on Q_{FA} may have been hidden by small subject number.

1. Introduction

Following the onset of exercise, blood flow (Q) increases through the conduit artery and the working muscle microvasculature to supply the O_2 needed for muscle metabolism. Previous research has shown femoral artery blood flow (Q_{FA}) kinetics to be faster than contracting muscle capillary blood flow (Q_{CAP}; Harper et al., 2006) kinetics, suggesting that a significant portion of Q_{FA} is not distributed to the capillaries of the working muscle. This discrepancy suggests there could be differences in the mechanisms associated with the increase in blood flow in these two locations. The initial, rapid increase in Q at exercise onset is thought to occur through the effects of the muscle pump and rapid vasodilation (Tschakovsky and Sheriff, 2004) but the exact contribution of each of these mechanisms is unknown. In contrast, the kinetics of increase in Q_{CAP} have been shown to be tightly coupled to the kinetics of the increase in muscle metabolism (Ferreira et al., 2005). This suggests that O_2 demand drives the increase in microvascular flow.

The kinetics of Q_{CAP} can be estimated by rearranging the Fick equation as follows (Ferreira et al., 2005):

$$Q_{CAP}(t) = \frac{VO_2\text{m}}{(CaO_2 - CvO_2)} \propto \frac{VO_2\text{p(Phase2)}(t)}{\text{deoxy[Hb + Mb]}(t)} \quad (1)$$

where Q_{CAP} is capillary blood flow, VO_2m is muscle oxygen uptake, (CaO_2–CvO_2) is the arterio-venous O_2 difference, VO_2p is pulmonary oxygen uptake and deoxy[Hb + Mb] is the deoxygenated hemoglobin plus myoglobin signal derived from near infrared spectroscopy (NIRS). This technique, first proposed by Ferreira et al. (2005), uses phase II VO_2p as a proxy measurement for VO_2m

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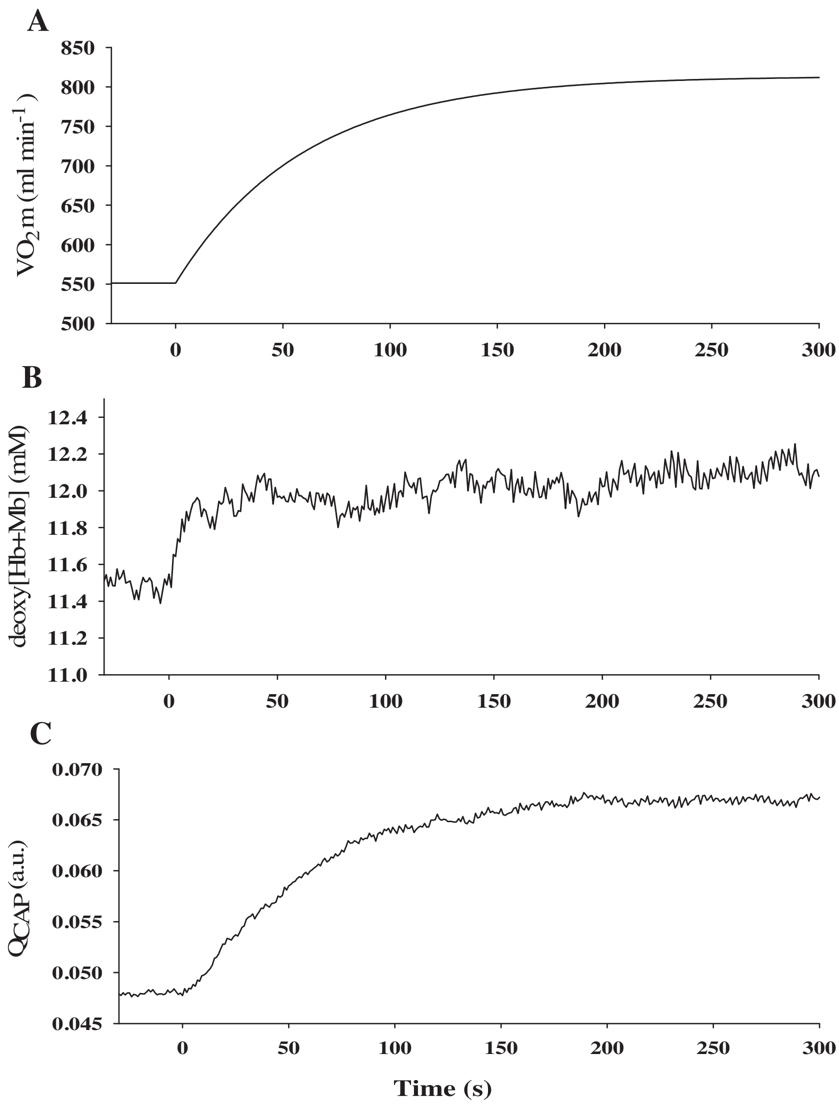

Fig. 1. Representative data from one subject during unloaded-to-loaded exercise transition.
A: VO_2m (ml min^{-1}) estimated from kinetic parameters of VO_2p during phase 2. B: deoxy(hemoglobin + myoglobin) concentration (deoxy[Hb + Mb], μM). C: estimated Q_{CAP} profile calculated by dividing VO_2m by deoxy[Hb + Mb]. The amplitude of Q_{CAP} is displayed in arbitrary units (a.u.) (Ferreira et al., 2005; Harper et al., 2006).

and deoxy[Hb + Mb] as a proxy measurement for the (CaO_2–CvO_2), making it possible to estimate Q_{CAP} kinetics noninvasively.

The Q_{CAP} estimation technique has been used during knee extension exercise to compare the changes in microvascular blood flow with those in the conduit artery. Harper et al. (2006) reported that the increase in Q_{CAP} following exercise onset was significantly slower than the change in deoxy[Hb + Mb] and Q_{FA}. The difference between Q_{CAP} and Q_{FA} was unexpected as the authors had hypothesized that during knee extension exercise, blood flowing through the femoral artery would be primarily going to the working muscle capillaries. From this finding arose the question, if blood flowing into the lower limb is not going to the working muscle capillaries, where is it going?

The purpose of the present study was to determine the mechanism(s) which produced the discrepancy between femoral artery blood flow kinetics and capillary blood flow kinetics seen by Harper et al. (2006). We utilized a protocol similar to that of Harper et al. (2006) but added cuffing below the knee to eliminate the contribution of the nonworking muscles and vasculature of the lower leg. Previous research has shown that cuffing below the knee during knee extension exercise does not change VO_2p (Andersen et al., 1985; Richardson et al., 1993), nor does it change leg blood flow (Richardson et al., 1993). Richardson, however, eliminated cuffing from his experiments stating that cuffing could slow the achievement of a physiological steady state. This suggests that cuffing below the knee could change the kinetics of VO_2p, Q_{FA} and Q_{CAP}. To our knowledge, no one has conducted systematic studies to test if cuffing below the knee influences the kinetics of VO_2p, Q_{FA} and Q_{CAP}. We hypothesized that during knee extension exercise, occluding below the knee would (1) slow the kinetics of adjustment of Q_{FA}, and (2) speed the kinetics of adjustment of Q_{CAP}, thus reducing any difference in the kinetics of Q_{FA} and Q_{CAP}.

2. Methods

2.1. Subjects

Six men age (mean ± SD) 25 ± 1.8 years; height 176 ± 7.5 cm; weight 83.8 ± 17.9 kg participated in the present study. All subjects were free of known cardiovascular, respiratory and metabolic disease, as determined by medical questionnaire, and were nonsmokers. The exercise protocol, benefits and risks of the study were