Optimal Hematocrit for Canine Skeletal Muscle During Rhythmic Isotonic Exercise

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Summary. Contractile power, blood flow, \( \text{O}_2 \)-uptake, and \( \text{O}_2 \)-extraction during isotonic, rhythmic exercise were determined in the isolated canine gastrocnemius muscle during perfusion with blood with hematocrits between 0.21 and 0.81. The results obtained in 36 measurements on nine muscles showed that maximal \( \text{O}_2 \)-delivery to the muscle is found at hematocrits between 0.5 and 0.6. Both in the range of hemodilution, and in the range of extreme hemoconcentration, \( \text{O}_2 \)-delivery decreases significantly. \( \text{O}_2 \)-consumption and contractile power of the muscles are almost unaffected in the hematocrit range between 0.4 and 0.7; beyond and below this hematocrit range both parameters decrease. \( \text{O}_2 \)-extraction is virtually constant in the hematocrit range between 0.3 and 0.6, but increases both below and above these hematocrit levels.

It is concluded that due to reduced vasodilatory reserve in working skeletal muscle compared to resting muscle the optimal hematocrit is shifted to higher values.

Key words: Skeletal muscle — Optimal hematocrit — Hemodilution — Hemoconcentration — Oxygen delivery — Dynamic work

Oxygen delivery to a tissue is defined as the product of blood flow and arterial \( \text{O}_2 \)-content. Both of these parameters are affected by changes of the hematocrit value (or hemoglobin concentration) of the flowing blood. Animal experiments and theoretical considerations have demonstrated that an optimum hematocrit can be defined at which \( \text{O}_2 \)-delivery is maximal. This optimal hematocrit was observed between 0.3 [20, 22] and 0.4 [24, 25, 29, 33].

It is, however, uncertain whether the value of the optimal hematocrit is the same under resting conditions and under conditions of increased \( \text{O}_2 \)-consumption (such as physical exercise). A reduction of the physiological hematocrit level may in fact lead to decreased \( \text{O}_2 \)-delivery; this conclusion can be drawn from studies demonstrating reduced work capacity during limited hemodilution [1, 12]. These results have, however, not been generally accepted [17]. On the contrary, studies performed
on human subjects have shown that acute elevation of the physiological hematocrit level may increase the aerobic work capacity [7]; these results have not been confirmed by other investigators [30, 36].

The value of the optimum hematocrit depends to a significant extent upon the change of blood flow resulting from hemodilution or -concentration [6]. The magnitude of blood flow changes is in turn a function of (a) the hematocrit-dependent alteration of blood viscosity, and (b) changes of vascular resistance. Consequently, it may be expected that in the absence of vascular changes the alteration of blood flow with hematocrit will be smaller and therefore the optimal hematocrit will be different when compared with a situation in which vascular resistance is not constant.

The present study was performed to establish the optimum hematocrit for skeletal muscle under conditions of exercise. In addition, contractile power and O2-uptake at varying arterial hematocrits were determined as parameters describing utilization of the oxygen delivered.

Materials and Methods

The experiments were carried out on nine mongrel dogs (body weight 11–15 kg) in pentobarbital anesthesia (Nembutal, 25 mg/kg). The animals were ventilated artificially, and end-expiratory CO2-concentration was continuously monitored (Uras 3, Hartmann und Braun, Frankfurt/Main). If needed, 0.3 M NaHCO3-solution was administered to prevent the development of metabolic acidosis.

Preparation

The experiments were conducted on the surgically isolated and autoperfused M. gastrocnemius. Surgical procedures were similar to those described previously [11, 16]. In essence, the left M. gastrocnemius was isolated and all side branches of the left femoral artery and vein were cut after ligatures, with the exception of those vessels feeding and draining the muscle itself. The left shank was amputated and the muscles of the thigh were removed. The N. ischiadicus was surgically exposed and cut so that its distal stump was long enough to allow indirect stimulation of the muscle. The femur was fixed to the experimental table and the achilles tendon was loaded with a weight of 0.5 kp during rest. To prevent drying, the muscle was wrapped with plastic foil; muscle temperature was monitored with a thermistor and maintained at 37°C using a heat lamp.

After heparinization (Vetren, 20 mg/kg body weight) the femoral artery was cannulated with PVC-tubing and connected to a perfusion system shown schematically in Figure 1. This system allowed alternate perfusion of the muscle either from the animal or from one of three transfusion bags containing arterialized donor blood with various hematocrits between 0.21 and 0.81. The transfusion bags were enclosed in a container pressurized by regulated water pressure to provide a constant perfusion pressure. Perfusion pressure was continuously monitored by a strain gauge transducer (Statham P23 Db, Statham Instr. Oxnard, Cal., USA), blood flow was measured by an electromagnetic flowmeter (Statham Model SP 2202). The arterial blood was maintained at a temperature of 37°C by use of a heat exchanger. Venous outflow from the gastrocnemius muscle was routed through PVC-tubing and an outflow orifice into a funnel from which it could either be returned to the femoral vein of the animal or discarded.

Perfusion Blood

To obtain the blood necessary to perfuse the muscle with varying hematocrit nine additional dogs (body weight 30–38 kg) were anesthetized (Nembutal, 25 mg/kg) and exsanguinated after cannula-