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ROLE OF DIFFERENCES IN MICROCIRCULATORY BLOOD FLOW VELOCITY IN OPTIMIZING PARAMETERS OF THE SKELETAL MUSCLE OXYGEN MODEL

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1. INTRODUCTION

Oxygen is the major substrate oxidizer in muscle fiber respiration. Its shortage induces functional-metabolic disturbances, namely, alteration of energy metabolism in cells. However, oxygen excess is also undesirable, being as a source of free radical oxidation reactions. The working range of oxygen concentration in skeletal muscle is limited and it is possible to speak of optimal pO_2 values. An optimal oxygen regimen (OR) in muscle tissue implies a reduction to minimum of areas with high and low tissue pO_2 values, irrespective of muscle motor activity. It was shown that the tissue O_2 supply is always sufficient for oxygen demand satisfaction[1]. At the same time, temporal-spatial heterogeneity of muscle pO_2, blood flow rate F (volume), or v (linear velocity) with changeable local capillarity is typical for the resting state. It creates oxygen mixing in tissues and the movement of hypoxic zones inside muscle if they occur. The action of local hypoxia depends on its degree and its duration. Thus the dynamics and heterogeneity of the microcirculation in specific cases may create either tissue pO_2 equalization or tissue damage, or training of the subcellular systems for hypoxic effects. It is suggested that blood flow heterogeneity is an important biophysical regulator of resting muscle OR on the level of the entire organ, creating the specific peculiarities of oxygen transport in muscle. The notion of blood flow heterogeneity within the microcirculation involves different blood flow velocities along muscle capillaries, and a variety of blood flow rates along vessels with different diameters, passing through muscle thickness and involved in oxygen transport. The first source of the pO_2 heterogeneity (and consequently the blood flow velocities) is the different vessel diameters and vessel interaction between each other due to their close proximity to each other.

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As far back as the 1970s, it was shown that at the wall of arterioles with a diameter of 25μm the pO_2 value was 60-70 mm Hg, and at arterioles with a diameter of 10μm it was 30-50 mm Hg[2,3]. Thus, the greatest leakage of oxygen on the way to the capillaries occurred through resistance vessels, the arterioles, and the pO_2 value in capillaries might be less than in veins. The intensity of extracapillary oxygen flux in tissue, as evidenced by data from experiments performed on muscle at resting conditions[3] may achieve approximately half of the overall muscle gas exchange values [3,4]. The aim of this study was to investigate the different typical microcirculatory situations in skeletal muscle and estimate the influence of blood flow heterogeneity in creating and maintaining optimal OR in skeletal muscle.

2. METHODS

The OR was studied using the mathematical model of convective and diffusion transport of O_2 to muscle tissue at steady state [5,6]. The model describes the muscle fiber amidst similar fibers, adjacent to it. This model operates with the values of the muscle blood flow velocity F, size and location of vessels, intervessel distances d_{AV}, intercapillary distance d_C, oxygen demand qO_2, the blood oxygen capacity and pH, oxygen content in the arterial blood, position and form of the oxyhemoglobin dissociation curve, the blood and tissue oxygen diffusion and solubility coefficients, as well as Km – the apparent Michaelis constant for oxygen. We used a biochemical criterion of hypoxia - the state when oxygen consumption rate $VO_2(x, y,z)$ becomes less than oxygen demand qO_2 because of the lack of oxygen at a point of tissue (x,y,z). That provides an opportunity to get a graphical image of tissue hypoxia. The calculated value of ratio $S(x,y,z)=VO_2(x,y,z)/qO_2x100(\%)$ describes the degree of hypoxia at (x,y,z). The surfaces Si(x,y,z) represent constant values of VO_2 (where $VO_2 < qO_2$) and map hypoxia in the muscle fiber (Figure1).

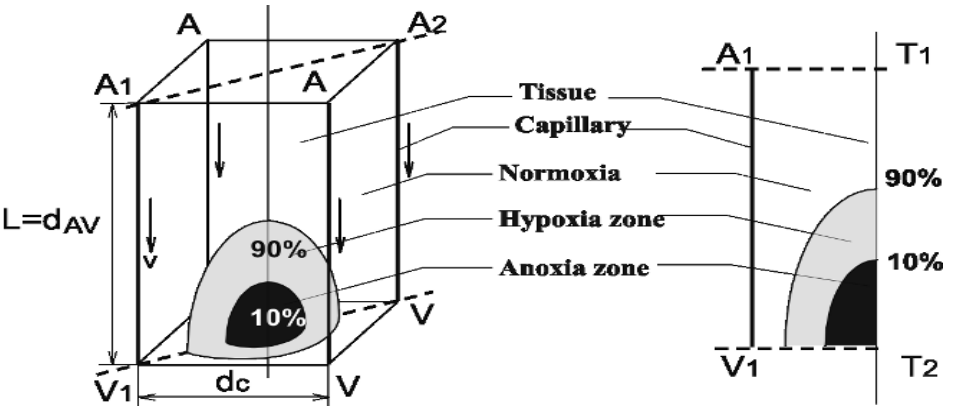

Figure 1. Model construction of muscle fiber with hypoxic zone inside; the model incorporates parts of the arteriole and venule, (shown by dotted lines) and capillaries. L- capillary length, A and V –capillary arterial and venous ends.