Microcirculatory Oxygen Transport and Utilization

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KEYWORDS

• Microcirculation • Oxygen transport • Oxygen utilization • Oxygen extraction • Capillary • Blood flow • Hemodynamics

KEY POINTS

- The microcirculation is a complex system designed to ensure that oxygen delivery meets or exceeds cellular oxygen demand.
- The cardiovascular system (macrocirculation) circulates blood throughout the body but the microcirculation, with its 10 billion capillaries, is responsible for modifying tissue perfusion and adapting it to metabolic demand.
- Hemodynamic assessment and monitoring of the critically ill patient is typically focused on global measures of oxygen transport and utilization, which do not evaluate the status of the microcirculation.
- Despite achievement and maintenance of global hemodynamic and oxygenation goals, patients may develop microcirculatory dysfunction with associated organ failure.
- A thorough understanding of the microcirculatory system under physiologic conditions will assist the clinician in early recognition of microcirculatory dysfunction in impending and actual disease states.

INTRODUCTION

Claude Bernard (1813–1878), a nineteenth-century French physiologist, was the first to publish a recognition that all higher-level organisms constantly strive to maintain internal homeostasis by actively controlling such variables as temperature, oxygen concentration, composition of ions, osmolality, and pH.[1] As strictly aerobic living

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organisms, human beings depend on oxygen for survival. As such, aerobic metabolism and organ function rely on the delivery and distribution of adequate amounts of oxygen. In the struggle against biological death from any cause, the battle is won or lost based on the restoration of adequate oxygen delivery ($\dot{D}O_2$) and oxygen consumption ($\dot{V}O_2$).[2] To accomplish this goal, a complex oxygen transport network involving the lungs, heart, macrovasculature, and microvasculature work in concert to receive oxygen from the environment and transport it to the tissues for utilization. Blood flow through the large blood vessels and microvasculature is referred to macrocirculation and microcirculation, respectively.

The microcirculation is a complex and integrated system that ensures oxygen delivery meets or exceeds cellular oxygen demand. The cardiovascular system, with its large arteries and veins, circulates blood throughout the body, but it is the microcirculation that regulates blood flow and distribution of red blood cells (RBCs) throughout individual organs.[3] Indeed, the microcirculation, with its 10 billion capillaries, is responsible for adjusting tissue perfusion to adapt to varying metabolic demands.[4] Despite this critical role, until recently the microcirculation has been neglected in practice. Hemodynamic assessment of the critically ill patient focuses on such global measures of oxygen transport and utilization such as cardiac output, arterial blood pressure, $\dot{D}O_2$, and $\dot{V}O_2$, none of which assesses the status of the microcirculation. Microcirculatory failure can occur despite the achievement and maintenance of normal, or even supranormal, systemic hemodynamic and oxygenation goals. A thorough understanding of the microcirculatory system under physiologic conditions is prerequisite to understanding the microcirculation in disease states. This article reviews the microcirculatory system, focusing on the anatomy and physiology of oxygen transport and utilization.

ANATOMY AND PHYSIOLOGY OF CIRCULATION

Broadly stated, the function of the heart and larger blood vessels is to pump and carry blood to and from the body's organs and tissues; the macrocirculation delivers blood to and receives blood from the microcirculation. The microcirculation, composed of specific vessels to be discussed subsequently, distributes the blood to regions of the body where it is needed and away from regions where it is not, then collects and returns it to the macrocirculation.[5]

Oxygenated blood leaving the pulmonary capillary system enters the left heart to be ejected to the systemic circulation. After leaving the heart, blood travels from the aorta to arteries that become progressively smaller until reaching the arterioles, then the capillaries, venules, and veins, each distinguished from each other by physical dimensions, characteristic morphology, and specific function.[1] Before blood travels back to the right heart, deoxygenated and ready to repeat the process, its real business has occurred during its course through the microcirculation. The microcirculation consists of the arterioles, capillaries, and venules. These vessels deliver and distribute oxygen, nutrients (eg, glucose and fatty acids), and inflammatory and coagulation factors to the tissues, and remove waste products of metabolism (eg, carbon dioxide and heat) (**Fig. 1**).[3,6]

Arterioles

The first vessels of the microcirculation are arterioles, which receive blood from arteries of the macrocirculation. Arterioles are referred to as resistance vessels because of their ability to constrict and dilate so as to regulate blood flow to individual organs. Arterioles have an endothelial lining with a thick smooth muscle layer and a thin