Microvascular Fluid Resuscitation in Circulatory Shock

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KEYWORDS

• Microcirculation • Shock • Hemodynamic coherence • Fluid • Oxygen transport

KEY POINTS

- The macrocirculation is the conduit for blood flow, whereas the microcirculation is responsible for fine-tuning capillary blood flow to maintain whole-body homeostasis.
- Microcirculatory shock persists after optimization of systemic hemodynamic measures.
- A loss of hemodynamic coherence between the macrocirculation and microcirculation exists in circulatory shock.
- Microcirculatory-guided fluid therapy based on direct visualization of the microcirculation is feasible to prevent the adverse outcomes associated with too little or too much fluid volume administration during resuscitation.

INTRODUCTION

In circulatory shock, cardiovascular optimization using fluid volume replacement is a widely accepted paradigm regardless of the shock subtype (hypovolemic, cardiogenic, obstruction, distributive). As one of the most common life-threatening conditions in critically ill patients, circulatory shock is an acute failure of the cardiovascular system to deliver sufficient oxygen to meet tissue oxygen demands. The result is tissue hypoxia with cellular dysfunction, organ dysfunction, and activation of anaerobic metabolism cellular pathways.

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Under physiologic conditions, a complex integrated oxygen transport network involving the lungs, heart, macrovasculature, and microvasculature efficiently move oxygenated blood from the environment to the tissues where oxygen is used for cellular metabolism and waste products are removed. Although the cardiovascular system circulates blood throughout the large arteries and veins (macrocirculation), the microcirculation is responsible for blood flow regulation and red blood cell (RBC) distribution throughout individual organs.[1] The microcirculation is essential to normal organ perfusion and functioning so it is now considered a distinct vital organ of the cardiovascular system,[2] which is remarkable considering that evidence of microcirculatory shock persists even after optimization of macrocirculatory hemodynamics.

Hypovolemia is a component in all subtypes of shock pathophysiology, making fluid resuscitation a cornerstone of therapy.[3] Typically titrated to macrovascular hemodynamic end points, the goal with fluid volume administration is to increase cardiac output (CO), thereby promoting adequate tissue perfusion and oxygenation. Conceptually, the basis for fluid administration is found at the level of the heart in the Frank-Starling law of cardiac performance; for a given increase in preload an increase in stroke volume and CO will result, thereby augmenting global forward blood flow. This macrocirculatory view assumes an increase in global blood flow parallels an increase in microcirculatory blood flow with improvements in cellular oxygenation. However, evidence now shows microcirculatory independence from macrovascular fluid administration in circulatory shock and especially in septic shock. This article discusses current understanding of changes in microvascular perfusion and oxygenation under hypovolemic conditions associated with circulatory shock, and insights into microcirculatory-guided fluid therapy.

Physiologic Microcirculatory Oxygen Transport and Use

The cardiovascular system is an elaborate, highly integrated oxygen transport system with the salient purpose of delivering adequate amounts of oxygen to the tissues to meet cellular oxygen demands and remove metabolic waste products. The large arteries and veins of the macrocirculation are tightly controlled by vascular, neural, hormonal, and biochemical processes to ensure matched bulk oxygen-rich blood delivery to the tissues to meet metabolic demands.[4] Once oxygenated blood from the pulmonary system enters the left heart it is pumped to the large arteries of the macrocirculation. Blood is deoxygenated in the microvascular system to then reenter the macrocirculation and travel through the large veins to the right heart to repeat the process. See **Fig. 1**. Although the macrocirculation is the conduit for blood flow, the microcirculation executes the detailed purpose of the cardiovascular system, which is to oxygenate tissues and organs to maintain homeostasis.

The most distal part of the circulatory system is the microcirculation, which includes the arterioles, capillaries, and venules. These smaller vessels deliver and distribute oxygen and nutrients to the tissues for metabolic use and then remove the metabolic waste. The first to receive blood from the macrocirculation are the arterioles. Because arterioles have a thick smooth muscle layer, they have the ability to constrict and dilate in order to precisely regulate blood flow to individual tissues and organs. The internal diameter of the arteriole is approximately 30 μm. Vessel diameter is important to note because it relates to blood flow velocity or rate.

The capillaries are the exchange vessels that receive oxygenated blood from the arterioles and distribute it to the tissues where it is needed. Oxygen is first chemically dissociated with the hemoglobin molecule and it then diffuses through the capillary wall to reach the cell. The cell organelle mitochondria then serve as energy factories