Basic Concepts of Hemorheology in Microvascular Hemodynamics

Shannan K. Hamlin, PhD, RN, ACNP-BC, AGACNP-BC, CCRN[a,*],
Penelope S. Benedik, PhD, RN, CRNA, RRT[b]

KEYWORDS

• Hemorheology • Microvascular • Hemodynamics • Viscosity
• Erythrocyte deformability • Erythrocyte aggregation • Blood flow • Tissue perfusion

KEY POINTS

- Blood rheology, or hemorheology, involves the science of flow and deformation behavior of blood and its formed elements (ie, erythrocytes, leukocytes, platelets).
- It is well known that the adequacy of blood flow to meet metabolic demands through large circulatory vessels depends highly on vascular control mechanisms.
- The extent to which rheologic properties of blood contribute to vascular flow resistance, particularly in the microcirculation, is becoming more appreciated.
- Current evidence suggests that microvascular blood flow is determined by local vessel resistance and hemorheologic factors such as blood viscosity, erythrocyte deformability, and erythrocyte aggregation. Such knowledge of the behavior of microvascular blood flow promises to be a significant benefit for clinicians who care for patients with hemodynamic alterations.

INTRODUCTION

The function of blood is to deliver oxygen and nutrients to every cell in the body and to remove waste products. To accomplish this, blood must transverse a complicated vascular network comprising vessel diameters ranging from 3 cm to 5 μm at a circulating flow rate sufficient to meet the metabolic demands of organs and tissue beds. The flow behavior of blood is a major determinant in oxygen delivery and tissue perfusion, and depends on the driving pressure generated by the heart, vascular hindrance (ie, diameter and length), and the rheologic properties of the blood. For centuries,

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[a] Nursing Research and Evidence-Based Practice, Houston Methodist Hospital, 6565 Fannin, MGJ 11-017, Houston, TX 77030, USA; [b] UT Health School of Nursing, University of Texas Health Science Center at Houston, 6901 Bertner Street, Room 682, Houston, TX 77030, USA
* Corresponding author.
E-mail address: SHamlin@HoustonMethodist.org

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scientists have investigated the vascular control mechanisms responsible for delivering oxygenated blood to tissues and organs. However, within the past 3 decades scientists have taken a strong interest in improving our understanding of blood rheology and tissue perfusion under dynamic conditions in the macrocirculation and microcirculation. Although global oxygen transport parameters such as cardiac output, oxygen delivery, and oxygen consumption are useful in determining the status of the cardiovascular system (macrocirculation), these parameters fail to provide insight into the state of the microcirculation, which is vital to tissue and organ function. In fact, hemorheologic disorders are among the most significant microcirculatory disturbances in the pathogenesis of hemorrhagic and septic shock. As such, it is important for clinical care staff to have an understanding of blood rheology, or hemorheology. This article discusses the basic concepts involved in hemorheology as it relates to blood-flow resistance in the microcirculation.

COMPOSITION OF BLOOD

Blood is a 2-phase fluid comprising various cells (ie, erythrocytes, leukocytes, platelets) and a liquid phase (ie, plasma) in which the cellular components of blood are suspended. The plasma is a complex solution of various materials (ie, proteins, lipoproteins, and metabolites) that make up approximately 9% of plasma by weight, the rest being water.[1] Under normal conditions plasma viscosity is generally thought to play a minimal role in flow resistance at the macrovascular or microvascular level. However, under pathologic conditions such as acute-phase reactions (ie, infection, postsurgical trauma), the increase in plasma proteins, especially fibrinogen, will contribute significantly to the nonspecific increase of plasma viscosity, with deleterious effects on blood flow in all circulatory vessels but especially those of the microcirculation.[1,2]

In relation to flow behavior, the red blood cells (erythrocytes) are the most prominent and influential component of blood at all levels of the circulatory system, either under bulk flow conditions in large blood vessels or in the microcirculation.[1,3] Their primary role is to facilitate the transport of oxygen and carbon dioxide to and from tissues and organs of the body. Erythrocytes are a single type consisting of a membranous sack containing a concentrated hemoglobin solution. For erythrocytes to survive in the harsh environment of the circulation, they must be able to rapidly undergo deformability and have extreme membrane stability when exposed to hemodynamic shear.[4] An erythrocyte will transverse the circulation more than 1000 times each day during its average 120-day life-span.[4]

Involved in defense against infection, white blood cells (leukocytes), on the other hand, are made up of several distinct varieties (ie, monocytes, granulocytes, and lymphocytes), all containing complicated interiors of organelles and a nucleus suspended in a viscous cytoplasm. Leukocytes play a small role in determining the viscosity of whole blood (ie, macrocirculation) because their number and volume concentration are much smaller than those of erythrocytes.[1] However, leukocytes play a major role in determining flow through the microcirculation for 2 reasons: (1) their internal content has greater viscosity and elasticity than that of the erythrocyte, and (2) all varieties of leukocytes are larger and stiffer, with slower deformability than the erythrocyte.[1] Leukocytes are slow and move erratically, which can delay and modify the capillary transit of the erythrocyte and influence microvascular resistance and tissue perfusion.[5]

Finally, platelets are all essentially similar in their composition; they are anucleated and have relatively complex contents of vacuoles and fibers suspended in a viscous