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Clarification on viscosity vs. viscoelasticity

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Dear Editor,

The excellent review by Pereira [1] provides a perspective on the history, physiology, and rationalization of blood volume resuscitation. More recently, a discussion of utilization of evidence-based bleeding management using rotational thromboelastometry by Görlinger [2] describes the persistent issues that arise when administering volume expanders and blood products following ratio-based regiments (e.g., 1 : 3 blood : crystalloid) in the setting of severe hemorrhage. He states that several centers, utilize a hybrid approach that address the problem of severe hemorrhage with a ratio-based regiment coupled with hemostatic interventions. Indeed, he concludes that resuscitation should follow a patient specific endpoint which addresses the set of circumstances unique to the patient in each setting. Our group believes that a key clinical parameter that utilizes a patient specific endpoint reflecting optimal oxygen delivery in capillary beds in the setting of resuscitation is needed. We propose that viscosity can play such a critical role in patient specific resuscitation.

When determining the clinical status of a patient suffering from a "shock" syndrome, including hypovolemic, cardiogenic, or septic shock, most physicians order a complete blood count (CBC) as an initial test. While giving significant information on the basic composition of one's blood, including cell number and hemoglobin, it fails to give significant information of the physical properties of the patient's blood. One of these properties that is gaining increasing attention is blood viscosity. Recent studies have shown that major regulators of circulatory physiology, e.g., the carotid sinus, may function through changes in blood viscosity rather through changes in blood pressure as a baroreceptor [3]. This hypothesis has the potential to pave the way for a different perspective of circulatory regulation that can directly affect patient outcomes, especially in circumstances where resuscitation of significant blood volume is required. However, there seems to be confusion amongst the medical community when it comes to terminology. Blood viscosity and viscoelasticity are often used interchangeably by many physicians, but they are distinct physical parameters. We believe that these terms require separate recognition. Therefore, the purpose of this letter is to clearly define blood viscosity and blood viscoelasticity as separate physiological parameters and further explain their clinical relevance and importance.

Viscosity can be simply defined as the resistance of a fluid against flow [4]. Most fluids have a constant viscosity that does not change with shear rate, classically defined as the rate of change in velocity as one layer of fluid passes over an adjacent layer. Air and water, for example, both exhibit this behavior and are therefore considered Newtonian fluids. Blood, on the other hand, is unique and does not exhibit Newtonian fluid dynamics. Its viscosity changes with shear rate, making it a non-Newtonian fluid. The viscosity dependence on shear rate arises from the complex composi-

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tion of blood with viscosity increasing at low shear rates and decreasing at high shear rates. Given that shear rate can directly influence viscosity, blood viscosity is different in large arteries, veins, and the microcirculation as the shear rate can vary anywhere between a few s^{-1} to more than 1000 s^{-1}. The significance of viscosity becomes apparent when one considers the primary stimulus of "endogenous production of NO within endothelial cells… is mainly regulated by shear stress (the product of shear rate times blood viscosity)" [5].

Blood viscoelasticity, on the other hand, refers to the elastic property that RBCs possess as they interact with one another, often expressed as an elastic modulus [6]. Unlike viscosity, viscoelasticity can be a function of the cell-to-cell interactions between RBCs that occur at low shear rates allowing them to deform, recover their shape, and form aggregates and complex 3-D structures [7]. Where viscoelasticity is a function of the interactions of RBCs to one another, viscosity is a more complete description of whole blood flow and delivery, making it a more holistic and robust clinical term.

The clinical importance of this distinction also requires recognition. It is the viscous properties of blood that are often seen in vivo such as the transition of blood flow from large to small diameter vessels or encounters at vascular bifurcations, like the carotid sinus [3]. This undoubtedly affects blood flow which can also manifest in disease. For example, increases in blood viscosity have been shown to play a significant role in the development of coronary artery disease [8]. Furthermore, the viscosity of blood has a significant relationship to outcomes in patient populations who demand effective and immediate resuscitation including patients suffering from burn shock [9] and acute coronary syndromes [10]. In conclusion, the distinction between blood viscosity and viscoelasticity is crucial, as it leads to a better understanding of the unique, non-Newtonian behavior of blood that is essential for local blood flow dynamics, which can be easily affected in hemodynamically unstable states. As an anesthesiologist making decisions for resuscitation in severe trauma or determining how to deal with unintended complications, this understanding can influence patient outcomes and survival.

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