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BIOLOGICAL FLUID VISCOSITY: PHYSIOLOGICAL BASIS, DETERMINANTS AND CLINICAL SIGNIFICANCE

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Abstract

Viscosity is a key physical property of biological fluids that determines their resistance to flow and directly influences circulation, tissue perfusion, and cellular transport. This article provides an in-depth analysis of the viscosity of biological fluids—primarily blood—integrating principles of fluid mechanics with physiological and clinical perspectives. The determinants of viscosity, including hematocrit, plasma protein concentration, temperature, and shear rate, are discussed alongside their role in normal physiology and disease states. Alterations in viscosity are shown to play a critical role in cardiovascular disorders, diabetes mellitus, and inflammatory conditions, making it an important diagnostic and prognostic parameter in modern medicine.

Keywords: viscosity, blood, shear stress, hematocrit, plasma proteins, hemodynamics

Introduction

Biological fluids, unlike ideal Newtonian fluids, exhibit complex flow behavior that reflects their heterogeneous composition. Blood, lymph, synovial fluid, and intracellular fluids all possess unique rheological properties that enable them to fulfill specialized physiological functions. Among these properties, viscosity—the internal resistance of a fluid to flow—is of central importance.

From a physical standpoint, viscosity arises from frictional forces between adjacent layers of fluid moving at different velocities. In the human body, this property ensures controlled blood flow through vessels, efficient nutrient delivery, and proper cellular interaction. However, deviations from normal viscosity can impair circulation and contribute to disease. Therefore, understanding the viscosity of biological fluids is essential for both basic science and clinical practice.

Materials and Methods

This work is based on a comprehensive analysis of medical and biophysical literature. Classical fluid dynamics principles were applied to biological systems, with particular emphasis on blood rheology. Parameters such as shear stress, shear rate, and dynamic viscosity were examined in relation to physiological and pathological conditions. Clinical data from hematology and cardiovascular studies were also incorporated.

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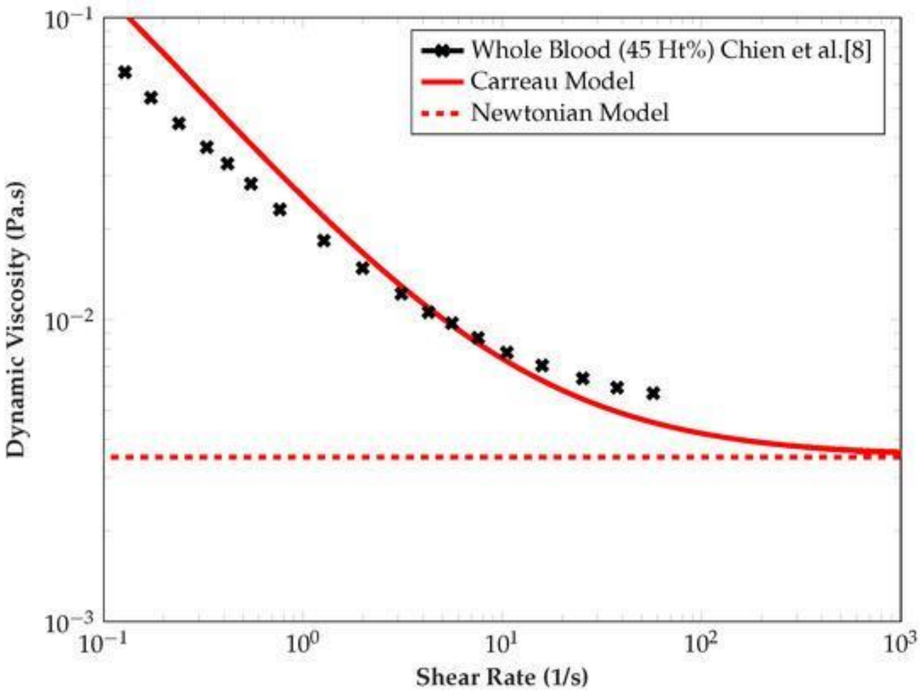
Results

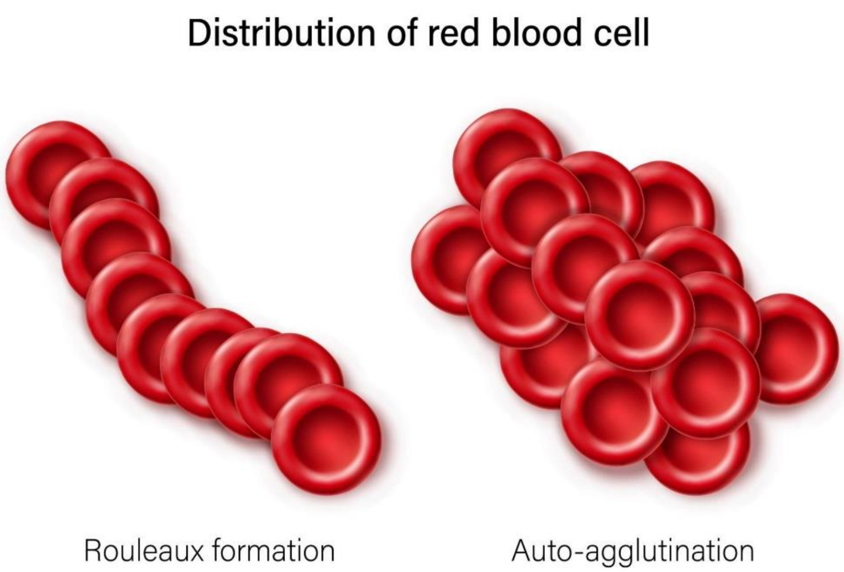
Viscosity is defined as the measure of a fluid's resistance to deformation under shear stress. In simple terms, it reflects how "thick" or "thin" a fluid is. This relationship can be mathematically expressed as:

\eta = \frac{\tau}{\dot{\gamma}}

where **η (eta)** represents viscosity, **τ (tau)** is shear stress, and **γ̇ (gamma dot)** is the shear rate.

In Newtonian fluids such as water, viscosity remains constant regardless of flow conditions. However, biological fluids—especially blood—are **non-Newtonian**, meaning their viscosity changes depending on the flow rate and shear conditions.





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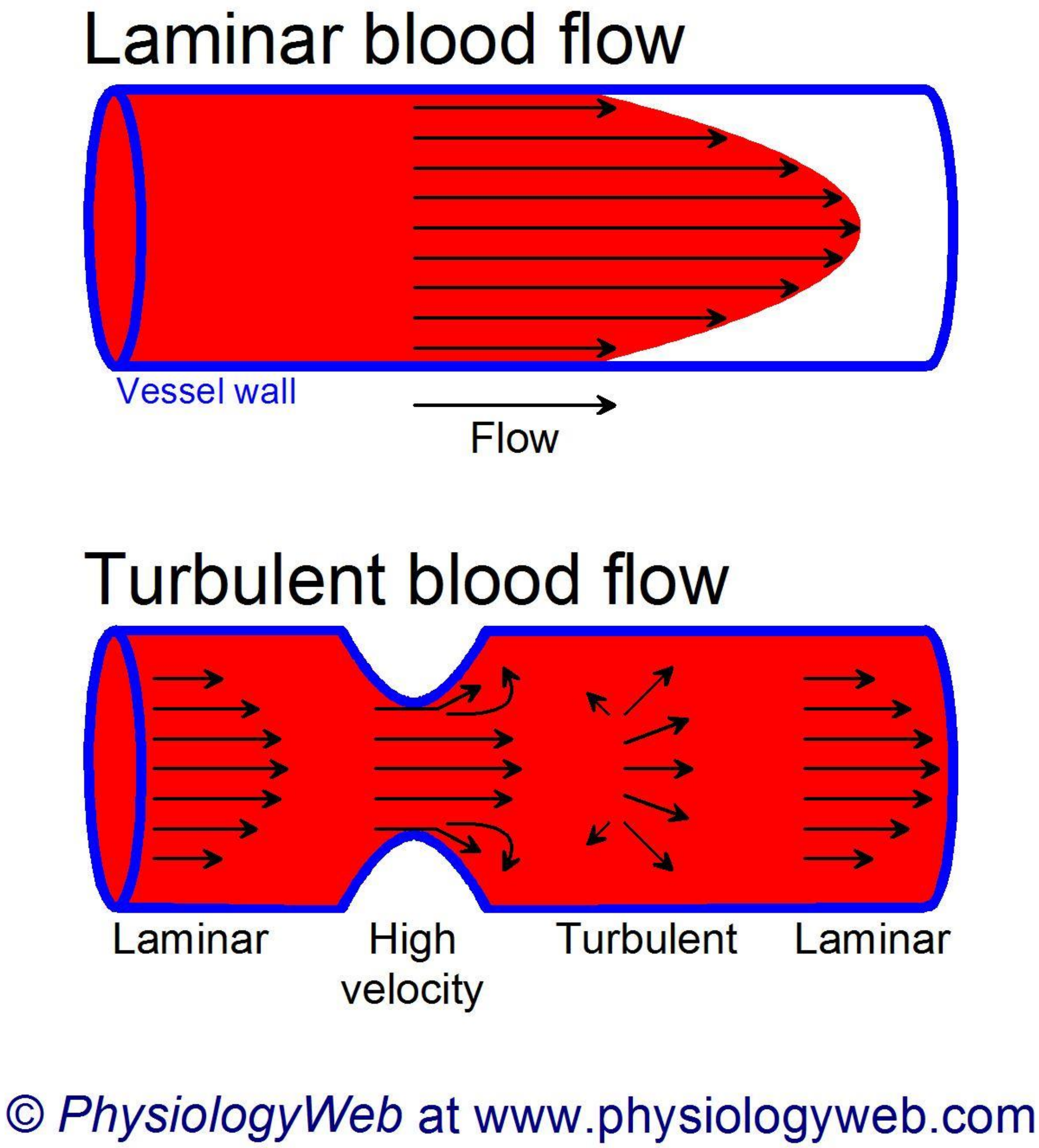

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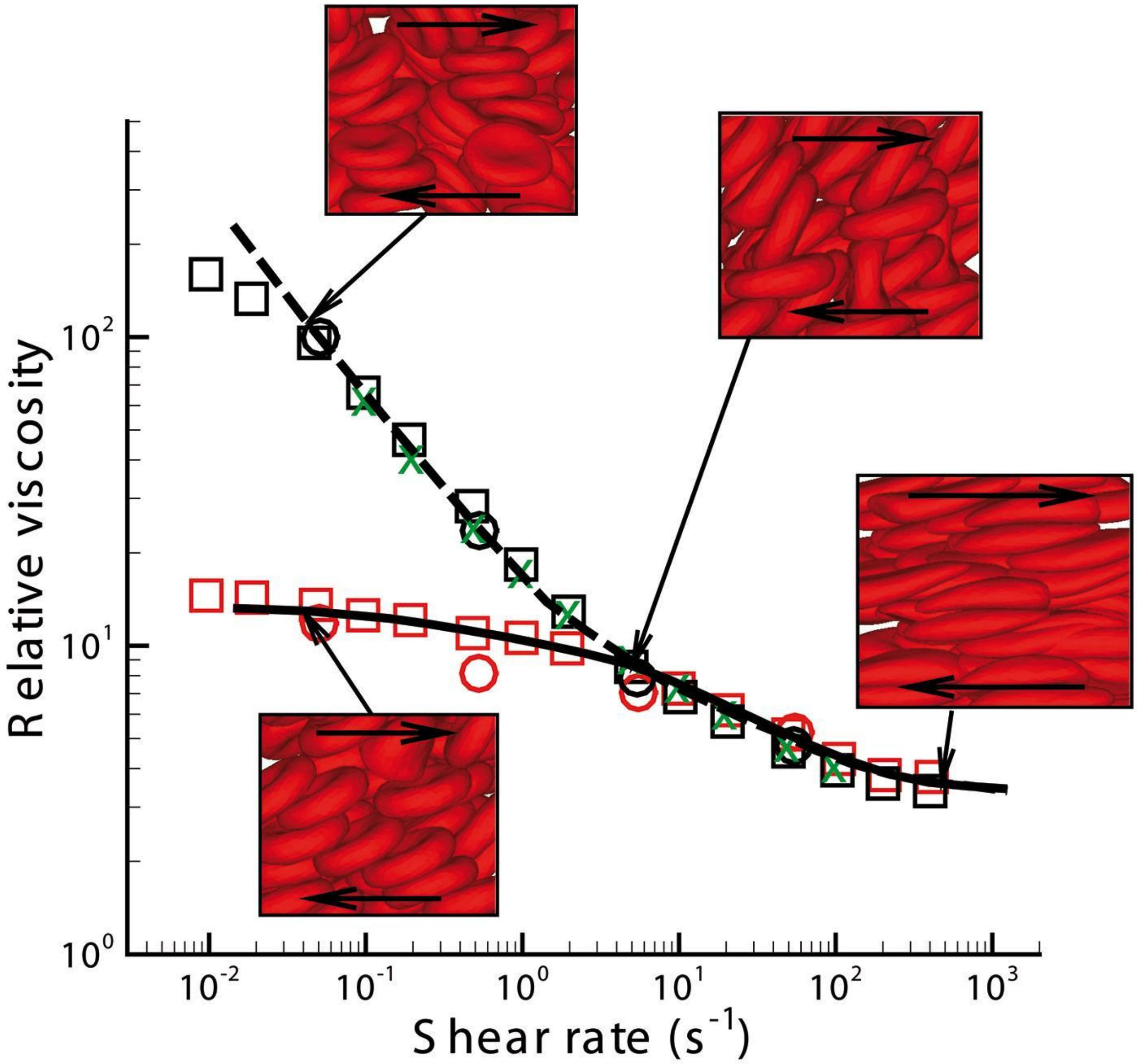
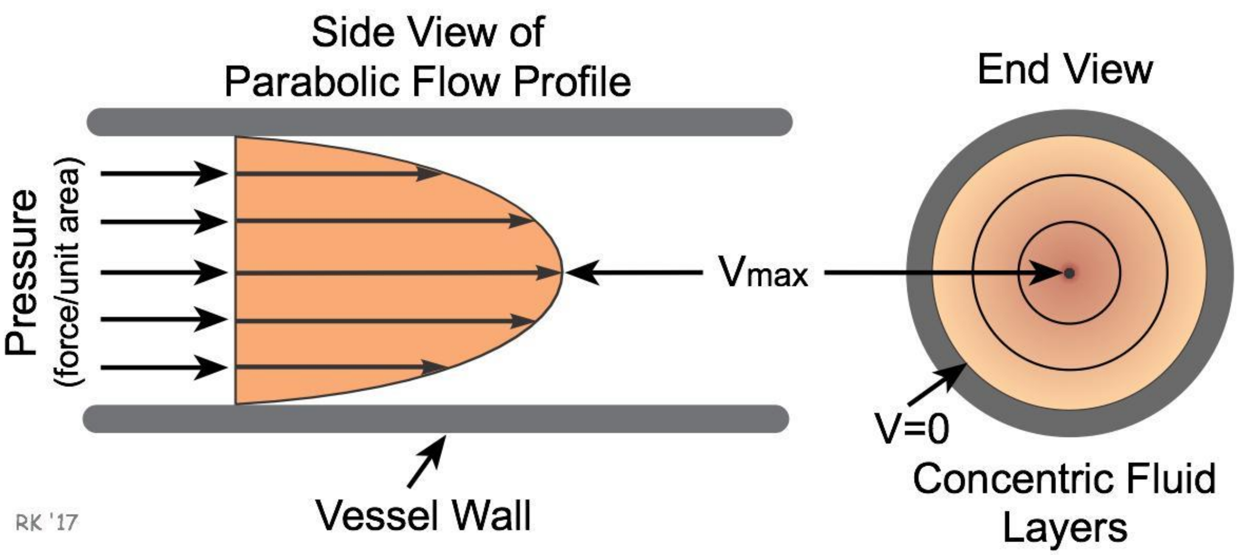
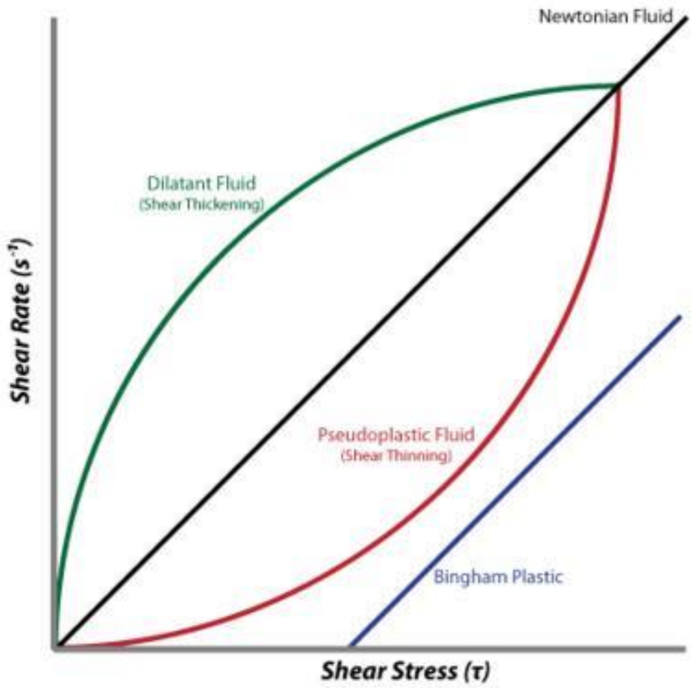
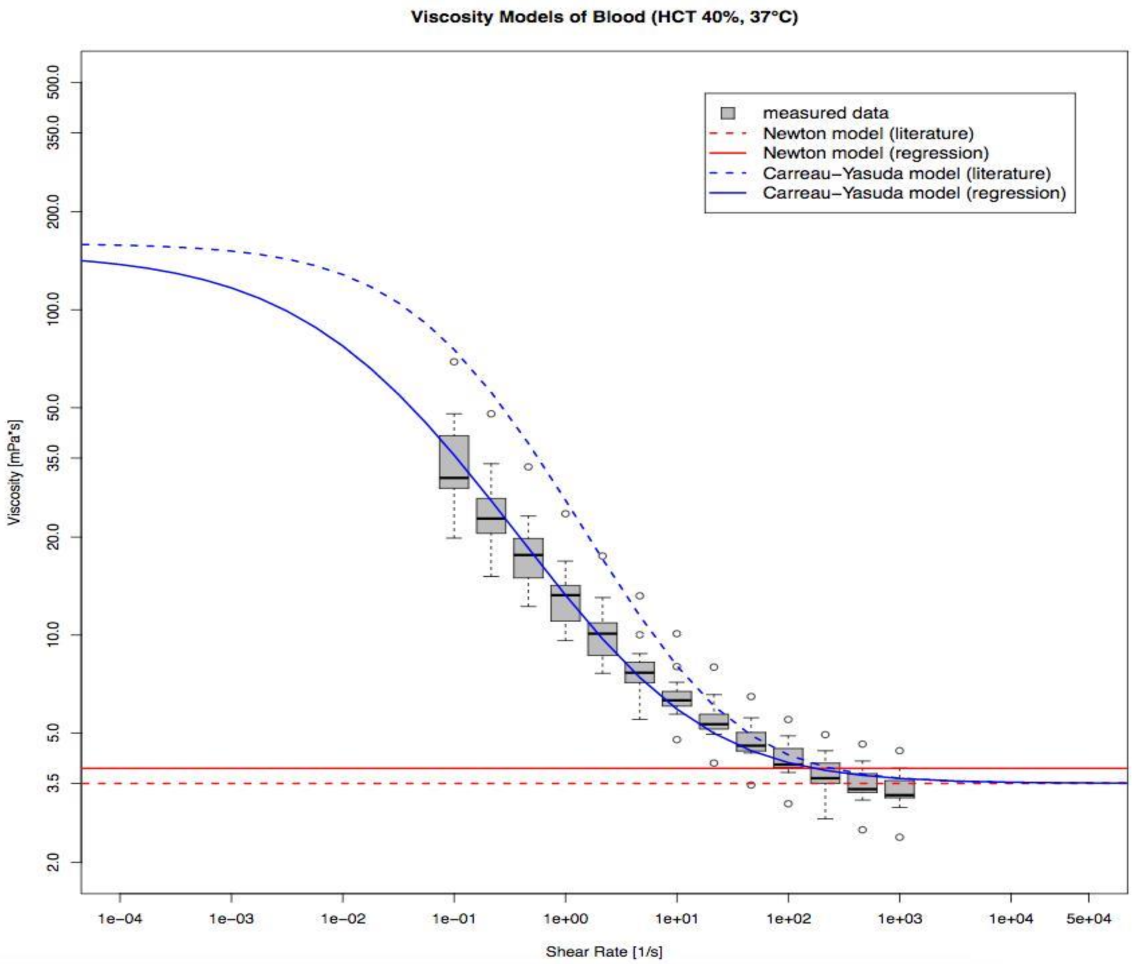


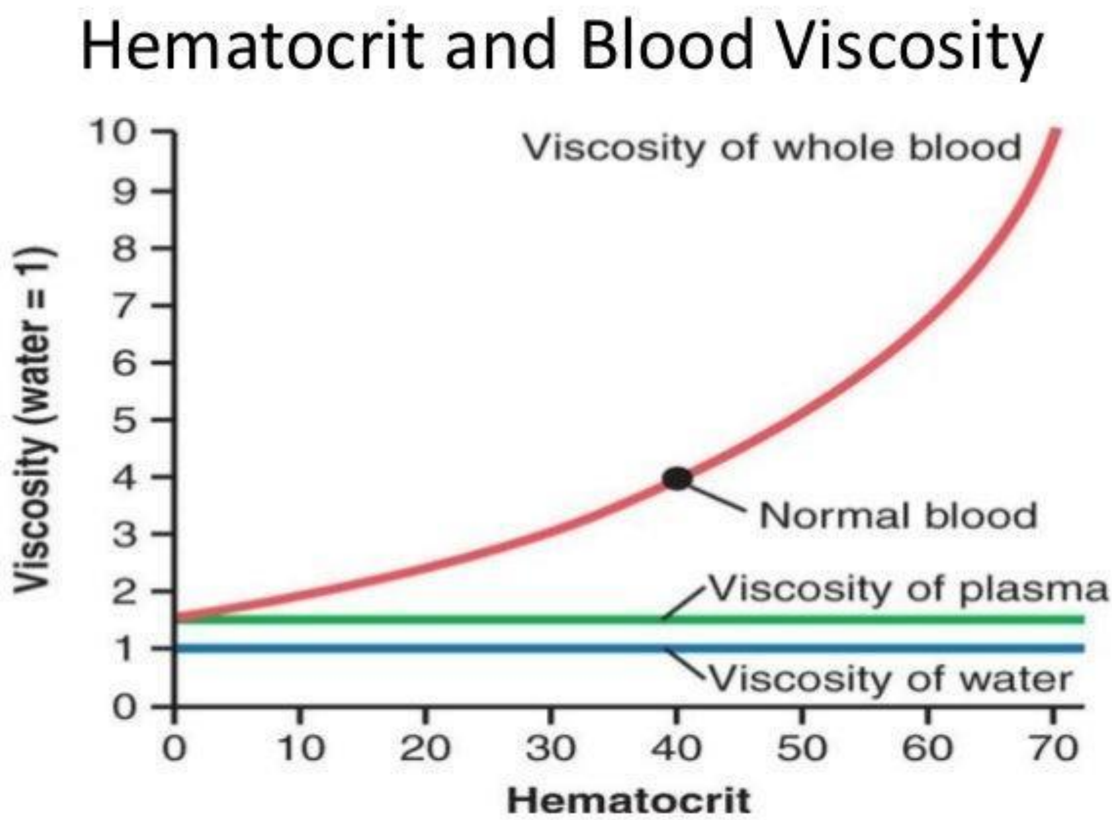



Newtonian Fluid
Dilatant Fluid
(Shear Thickening)
Pseudoplastic Fluid
(Shear Thinning)
Bingham Plastic
Shear Rate (s⁻¹)
Shear Stress (τ)


Viscosity Models of Blood (HCT 40%, 37°C)
measured data
Newton model (literature)
Newton model (regression)
Carreau–Yasuda model (literature)
Carreau–Yasuda model (regression)
Viscosity [mPa*s]
Shear Rate [1/s]
2.0
3.5
5.0
10.0
20.0
35.0
50.0
100.0
200.0
350.0
500.0
1e−04
1e−03
1e−02
1e−01
1e+00
1e+01
1e+02
1e+03
1e+04
5e+04

Blood viscosity is influenced by several key factors. One of the most significant is **hematocrit**, which represents the proportion of red blood cells in blood. An increase in hematocrit leads to higher viscosity due to increased cellular interactions and friction. Plasma proteins, particularly fibrinogen, also contribute to viscosity by promoting aggregation of erythrocytes, forming structures known as rouleaux.

Temperature is another important determinant. As temperature decreases, viscosity increases due to reduced molecular motion. This explains why peripheral circulation may be impaired in cold environments. Additionally, shear rate plays a crucial role: at low shear rates, red blood cells tend to aggregate, increasing viscosity, while at high shear rates, they deform and align with flow, reducing resistance.



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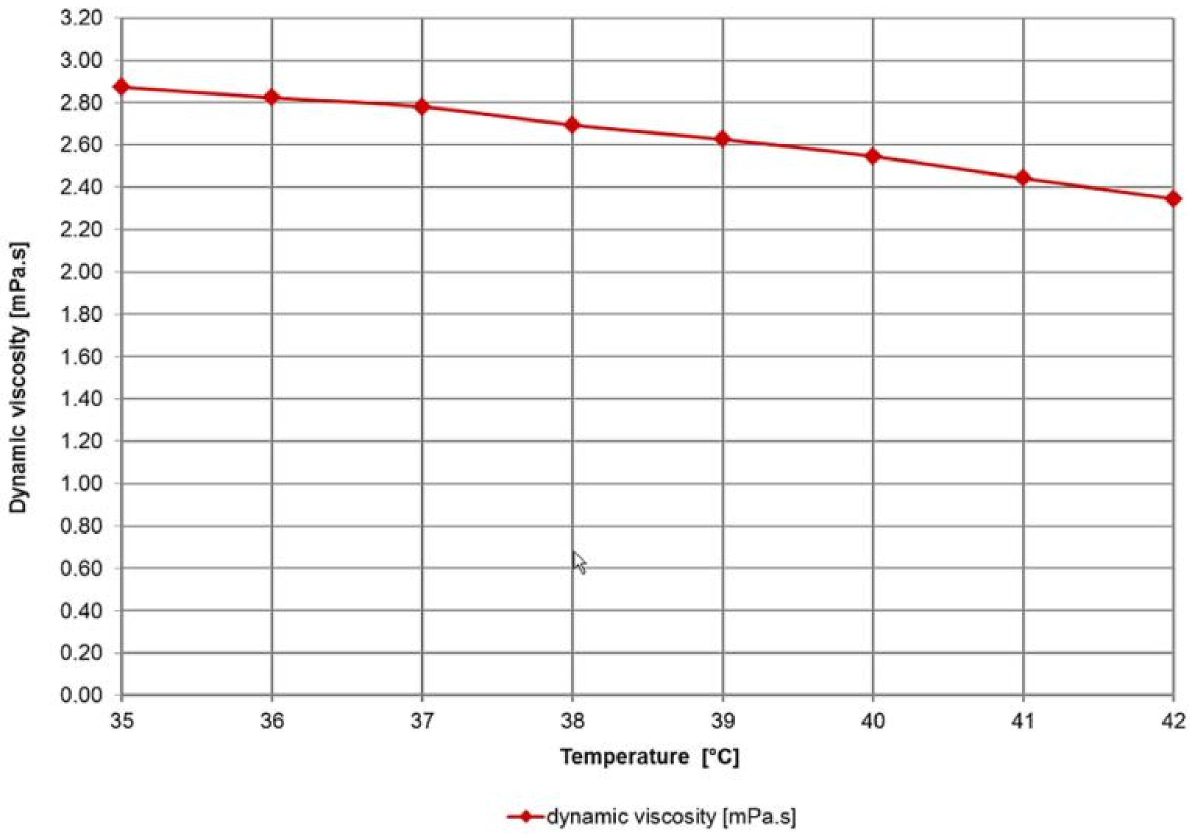

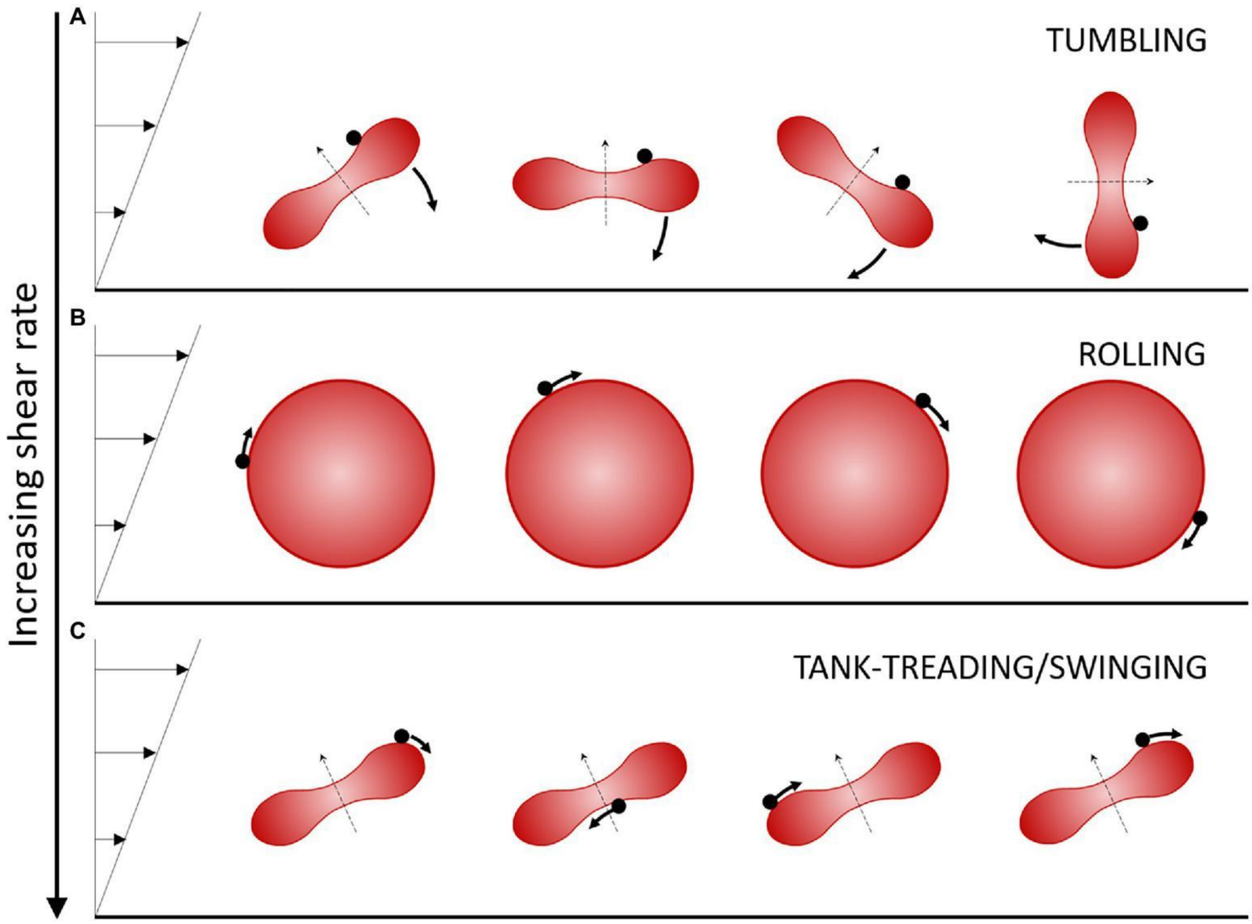

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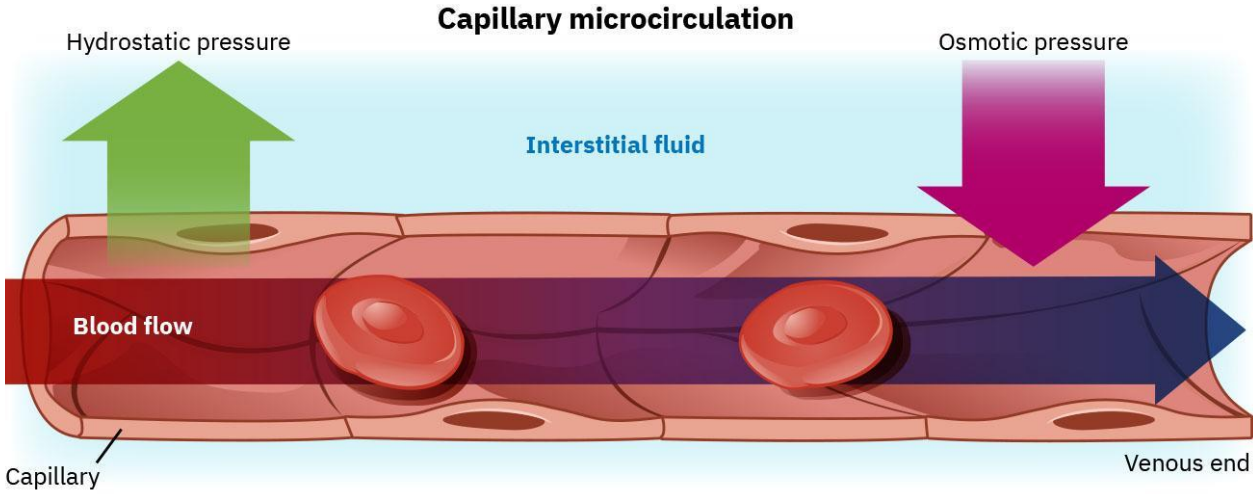

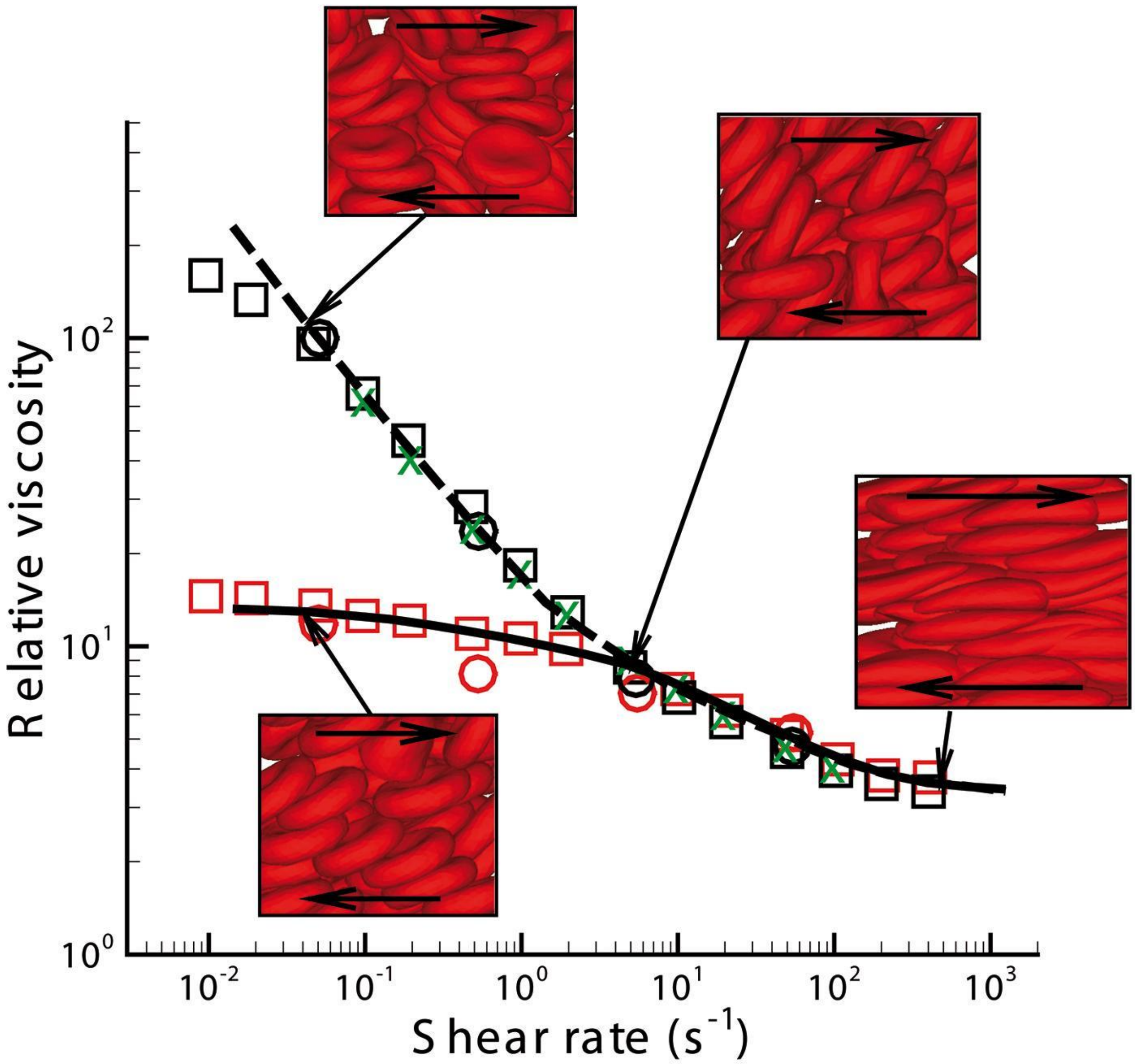

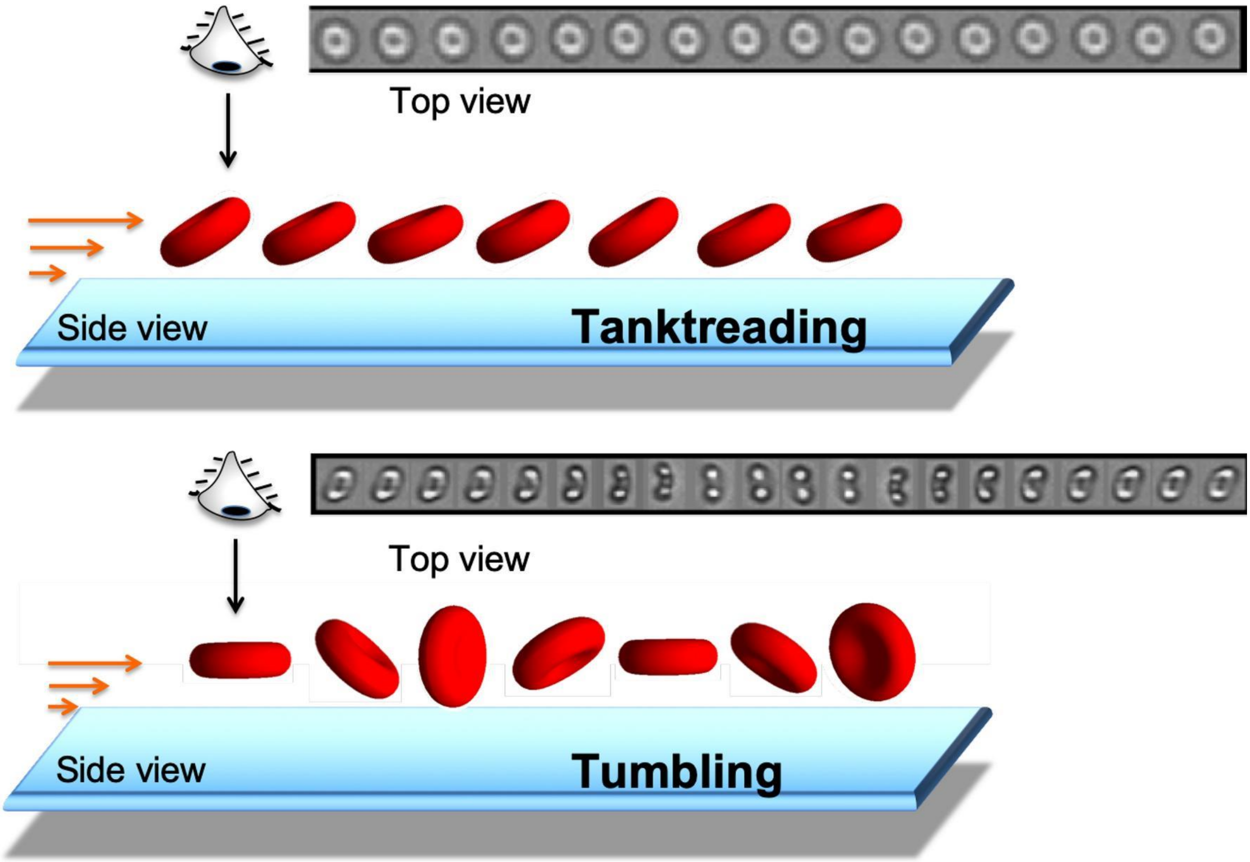

Other biological fluids exhibit distinct viscosity characteristics. Synovial fluid, for example, is highly viscous due to hyaluronic acid content, enabling lubrication of joints. Mucus viscosity is essential for trapping pathogens, while cerebrospinal fluid has relatively low viscosity to facilitate circulation within the central nervous system.

Discussion

The viscosity of biological fluids plays a crucial role in maintaining physiological homeostasis. In the cardiovascular system, optimal blood viscosity ensures efficient perfusion without excessive cardiac workload. Increased viscosity, as observed in conditions such as polycythemia or dehydration, can lead to elevated vascular resistance, reduced blood flow, and an increased risk of thrombosis.

Conversely, decreased viscosity, which may occur in anemia, can impair oxygen delivery despite improved flow dynamics. In diabetes mellitus, changes in plasma composition and erythrocyte deformability alter blood viscosity, contributing to microvascular complications such as retinopathy and nephropathy.

From a clinical perspective, viscosity is not only a diagnostic parameter but also a therapeutic target. Interventions such as hydration therapy, anticoagulation, and plasma exchange are aimed at optimizing blood rheology. Moreover, advances in biomedical engineering have led to the

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development of artificial blood substitutes and perfusion systems that mimic natural viscosity properties.

Conclusion

Viscosity is a fundamental property of biological fluids that significantly influences physiological function and disease processes. Blood, as the most clinically relevant fluid, exhibits complex, non-Newtonian behavior that depends on multiple interacting factors.

A comprehensive understanding of fluid viscosity provides valuable insights into cardiovascular health, metabolic disorders, and systemic diseases. Integrating physical principles with clinical knowledge enhances the ability of healthcare professionals to diagnose, manage, and prevent conditions associated with abnormal fluid dynamics.

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