Dynamics of Red Blood Cells in Shear Flow: From Experimental Observations to Clinical Applications

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Introduction

Red blood cells (RBCs) are principal actors in our circulatory system. Each RBC consists of a deformable lipid bilayer supported by a thin elastic cytoskeleton, encapsulating a Newtonian hemoglobin solution. RBCs constitute about 45% of blood volume, making them key players in blood rheology. In RBC-related diseases (hemoglobinopathies), the mechanical properties of these cells are altered, which can have serious consequences.

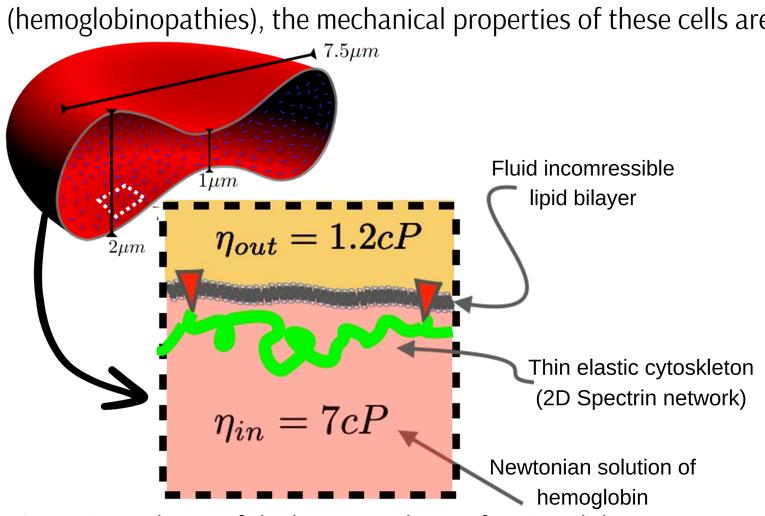


Figure 2: *A schema of the biancove shape of RBC and the its inner structure.* ***[1]***

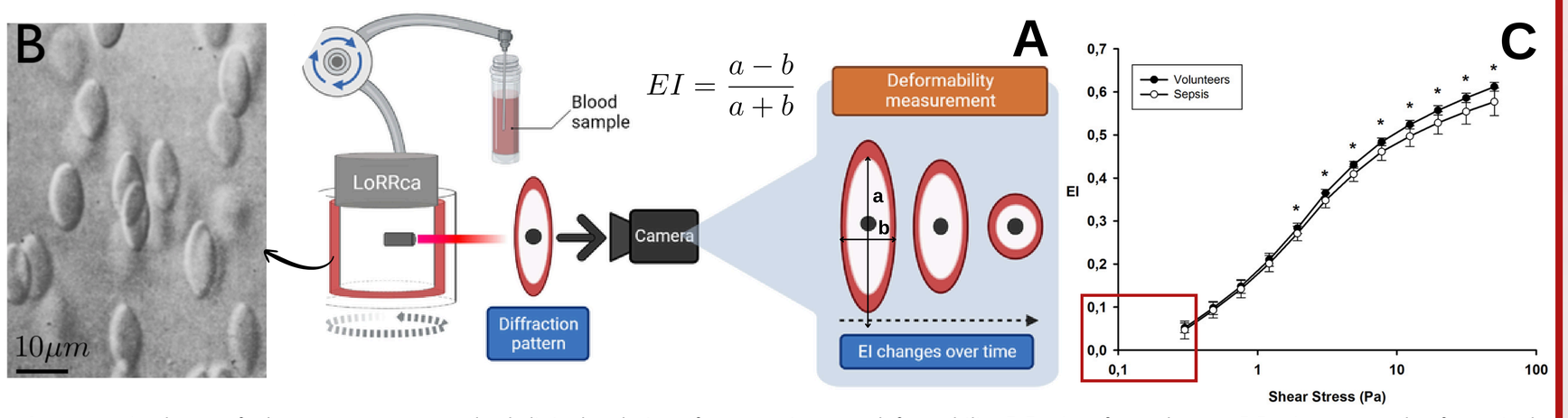


Figure 3: *A) schema of ektacytometry, a standard clinical technique for assessing RBC deformability* ***[3].*** *B) Deformed RBCs* ***[1].*** *C) An example of a typical trace of the elongation index from ektacytometry measurements* ***[3].***

Methods & Experiments

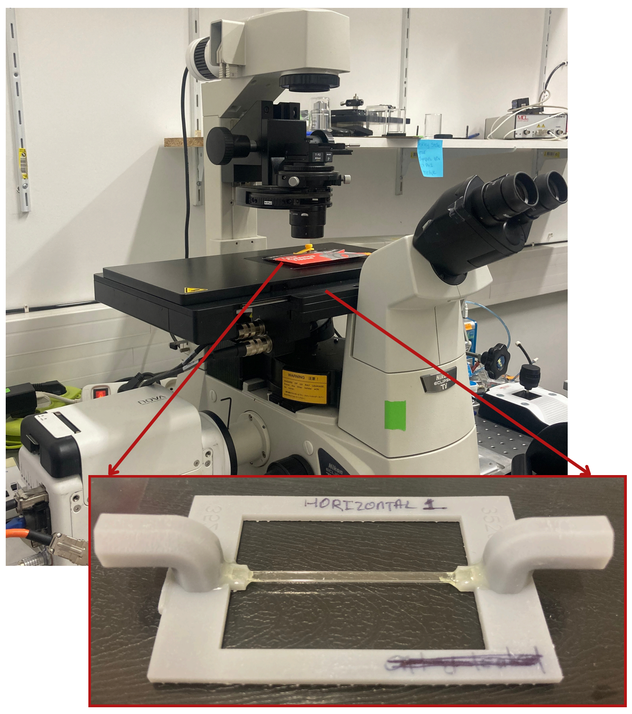


Figure 4: Experimental Setup. *A microscope equipped with a high-speed camera is used to observe the flow. The flow channel consists of a glass capillary held in place by a 3D-printed support, the camera captures the top view during experiments.*

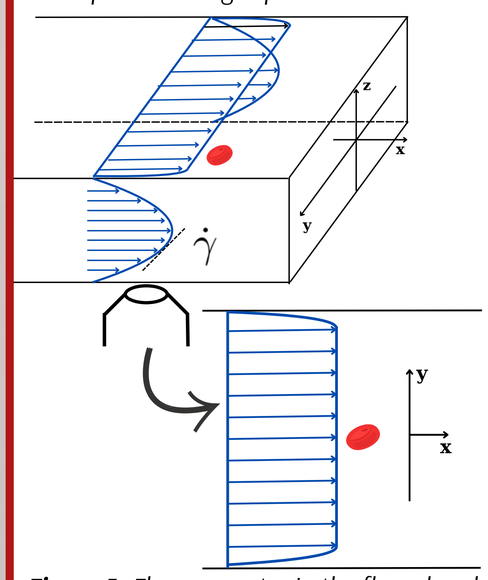
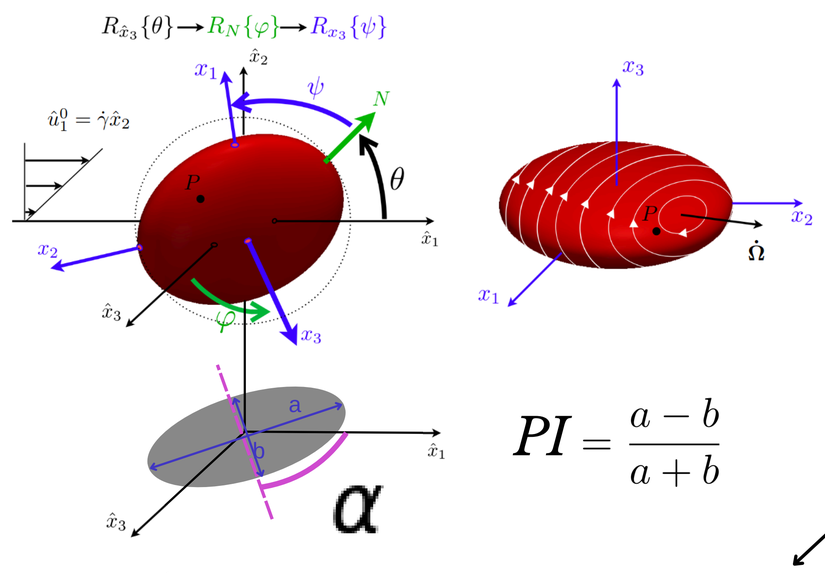


Figure 5: *Flow geometry in the flow chamber*

Figure 6: *Respresentation of RBC in shear flow with 3D shape preserving model* ***[1].***



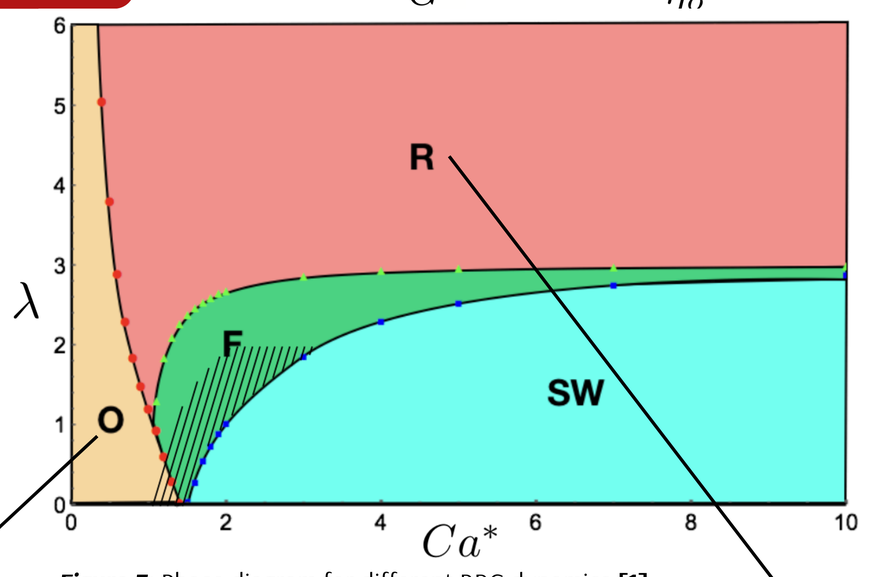


Figure 7: Phase diagram for different RBC dynamics **[1].**

Image Analysis & Kalman Filter

$\dot{\gamma} = 12.5s^{-1}$ $Ca^* \approx 0.17$ $\lambda \approx 11$ **Orbiting**

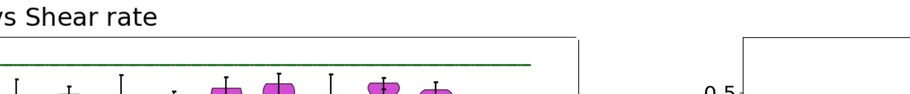
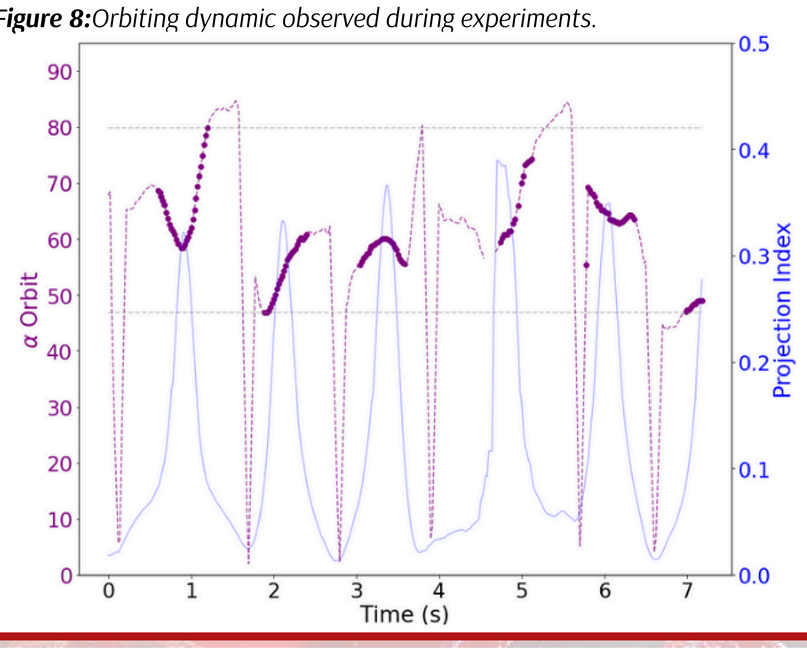


Figure 8:*Orbiting dynamic observed during experiments.*



$\dot{\gamma} = 50.0s^{-1}$ $Ca^* \approx 0.8$ $\lambda \approx 11$ **Rolling**

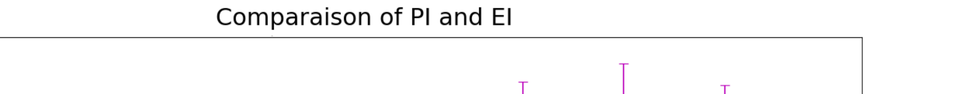
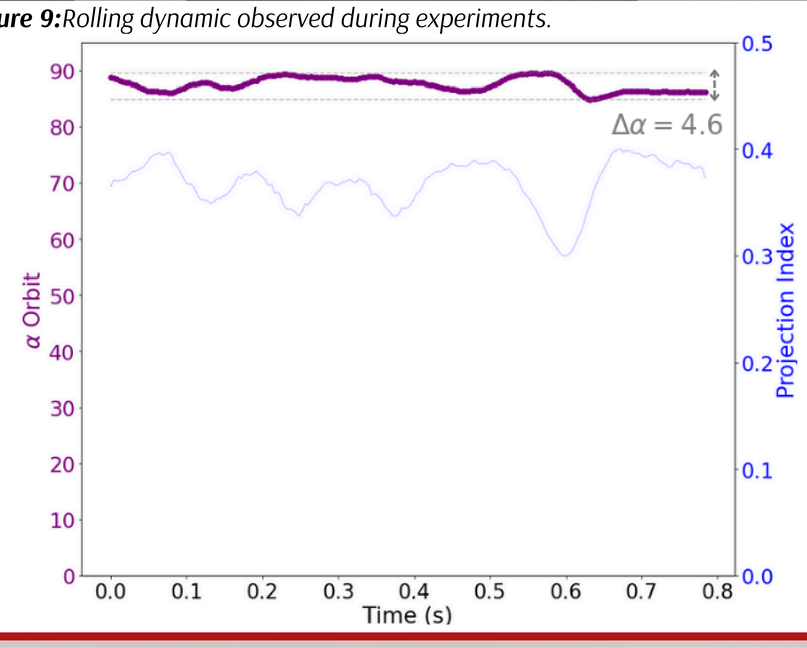


Figure 9:*Rolling dynamic observed during experiments.*



Results & Future Directions

We will compare our single-cell observations with clinical methods based on population-level analysis, with the goal of identifying intrinsic mechanical parameters of RBCs from extrinsic flow behavior.

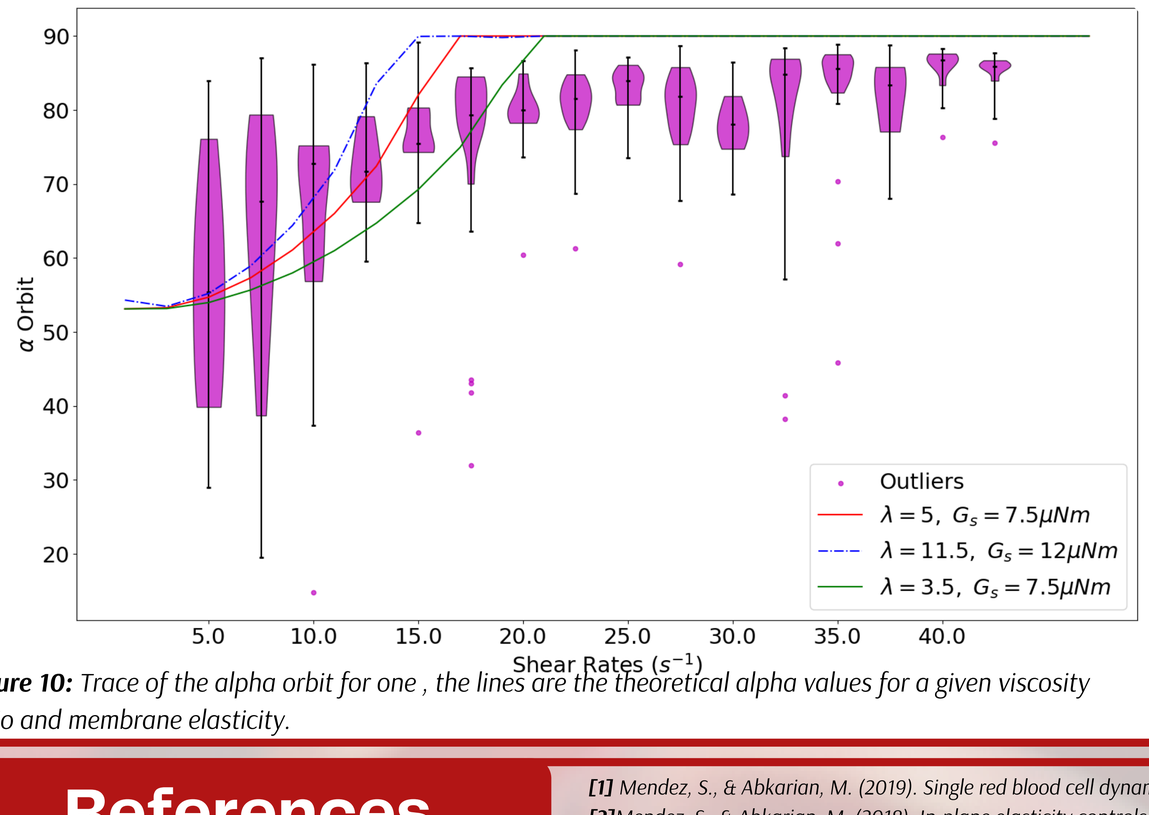


Figure 10: *Trace of the alpha orbit for one , the lines are the theoretical alpha values for a given viscosity ratio and membrane elasticity.*

Figure 11: *Elongation index obtained by ektacytometry and projection index obtained from flow chamber experiments. Blue continuous line is the prediction of the 3D model.*

References

[1] *Mendez, S., & Abkarian, M. (2019). Single red blood cell dynamics in shear flow and its role in hemorheology. Stress, 5, 2-3.*

[2]*Mendez, S., & Abkarian, M. (2018). In-plane elasticity controls the full dynamics of red blood cells in shear flow. Physical Review Fluids, 3(10), 101101.*

[3] *Larkin, S. K. et al. (2024). The RoxyScan is a novel measurement of red blood cell deformability under oxidative and shear stress. Scientific Reports, 14(1), 6344.*