Quantitative assessment of lipid bilayer-cytoskeleton coupling in red blood cell membrane

V. Puthumana, Paul G. Chen, Marc Leonetti, R. Lasserre, Marc Jaeger

Quantitative assessment of lipid bilayer-cytoskeleton coupling in red blood cell membrane

V. Puthumana[1], P. G. Chen[1], M. Leonetti[2], R. Lasserre[3], and M. Jaeger[1]

[1]Aix Marseille Univ, CNRS, Centrale Marseille, M2P2, Turing Centre for Living Systems, France
[2]Aix Marseille Univ, CNRS, CINaM, Turing Centre for Living Systems, Marseille, France
[3]Aix Marseille Univ, INSERM, CNRS, CIML, Turing Centre for Living Systems, Marseille, France

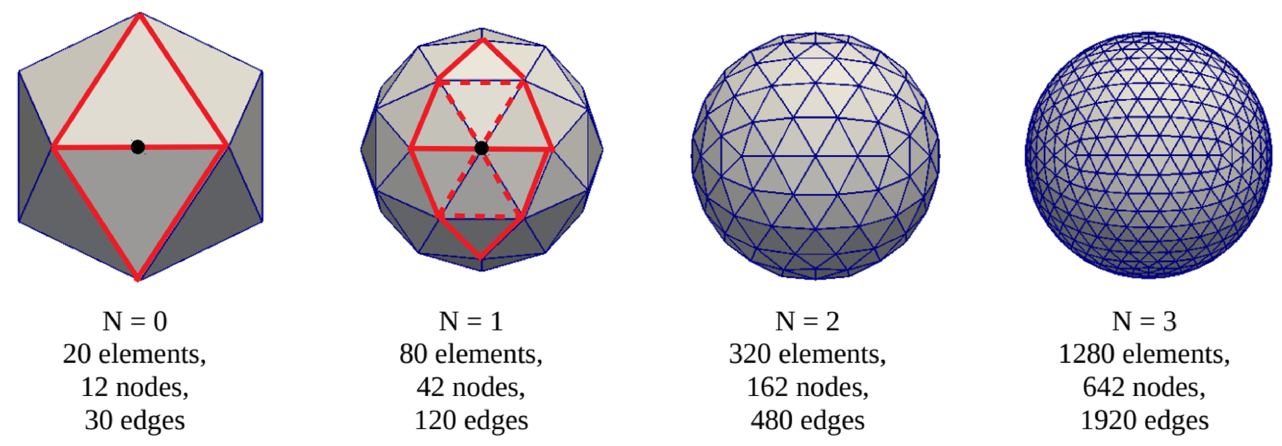
Scan for full article

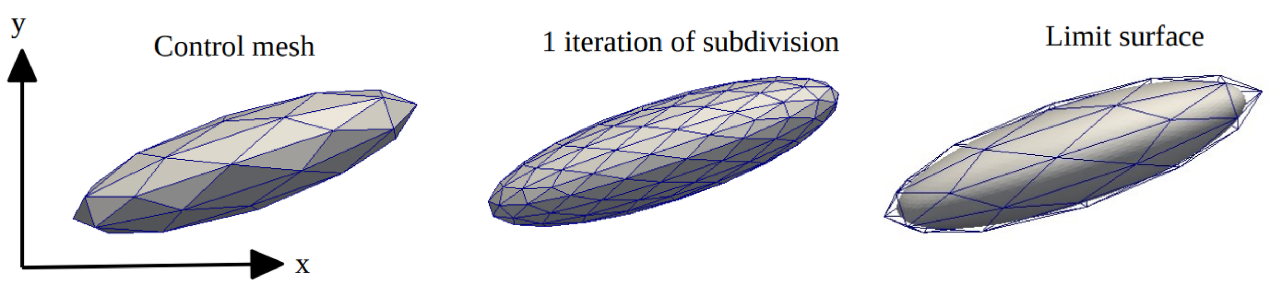
Overview

Like other cells, the RBC membrane is composed of a lipid bilayer (BL) supported by a cytoskeleton (SC). The BL provides fluidity, area incompressibility and slight resistance to bending. The SC provides shear elasticity. The coupling of the SC to the BL is provided by protein junction complexes, with possible sliding. Despite this biological reality, the most commonly adopted modelling strategy is of the capsule type[1], representing the SC and the BL in only one solid layer. To quantify the consequences of this simplification, we compare Capsule (C) and Vesicle (V) models with models that distinguish the bilayer from cytoskeleton by a combination of Capsule-Capsule (C-C) and Vesicle-Capsule (V-C), as well as Capsule-Spring (C-S) and Vesicle-Spring (V-S) on the typical dynamic regimes (Ca, λ) observed for shear flow.

C → Blue   C-S → Green   C-C → Cyan   V → Black   V-S → Orange   V-C → Red

Modelling strategy[2,3]





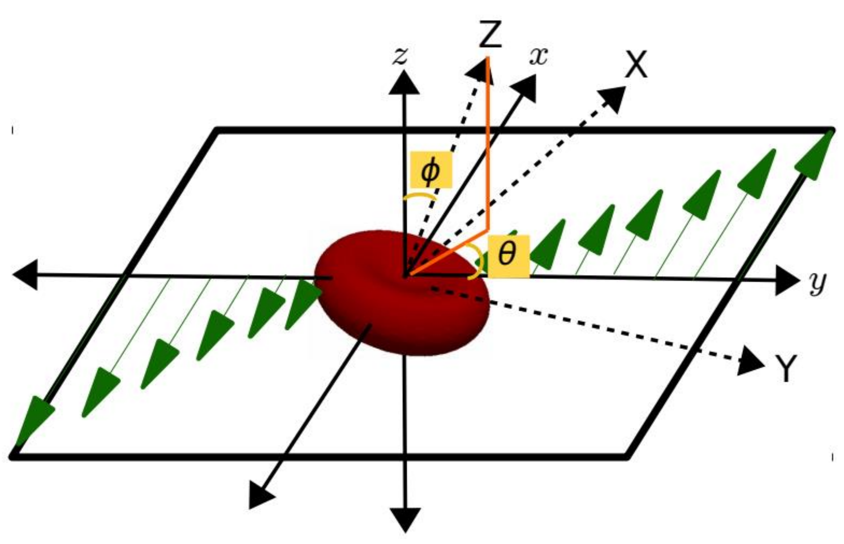
$$\mathbf{v}^{BL} = \mathbf{P}\left(\mathbf{v}^{\infty} + \mathbf{G}\mathbf{f}^{RBC}\right), \quad with \quad \mathbf{f}^{RBC} = \mathbf{f}^{BL} + \mathbf{f}^{SC}$$

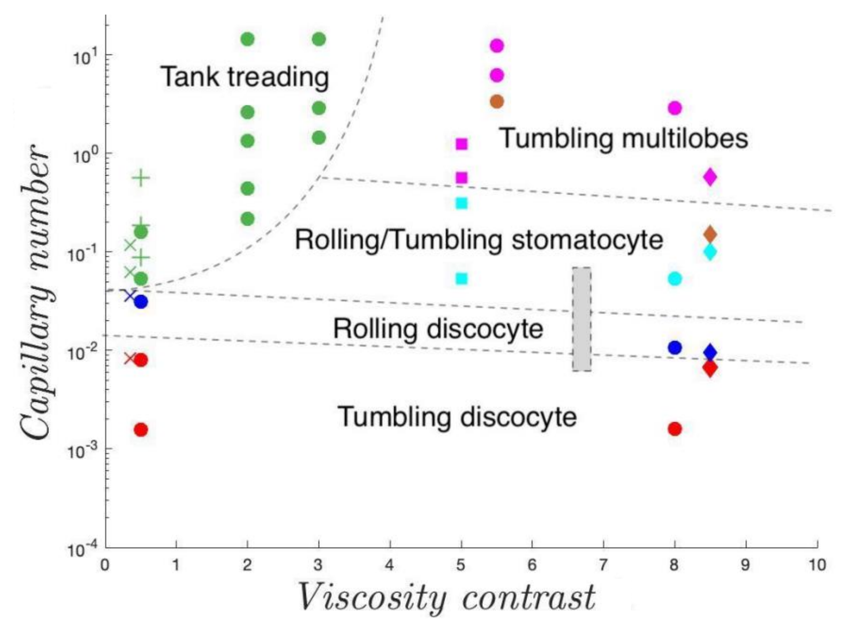
$$\mathbf{x}(t+dt) = \mathbf{x}(t) + dt\,\mathbf{v}^{SC}$$

$$\mathbf{f}(\mathbf{x}) = -\frac{\delta W}{\delta \mathbf{x}}, \quad for\ capsule\ and\ vesicle$$

$$\mathbf{f}(\mathbf{x}) = \sum_{n=1}^{N_{node}} \mathbf{F}_n \delta_{\mathbf{x}_n}(\mathbf{x}), \quad \mathbf{F}_n = \sum_p K_{np}(\mathbf{x}_p - \mathbf{x}_n), \quad for\ spring$$

Comparison in shear flow[3,4,5,6]

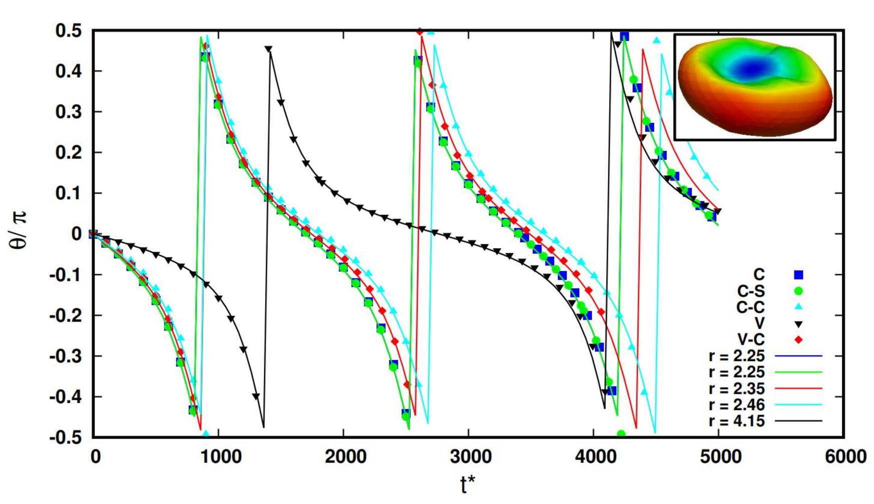


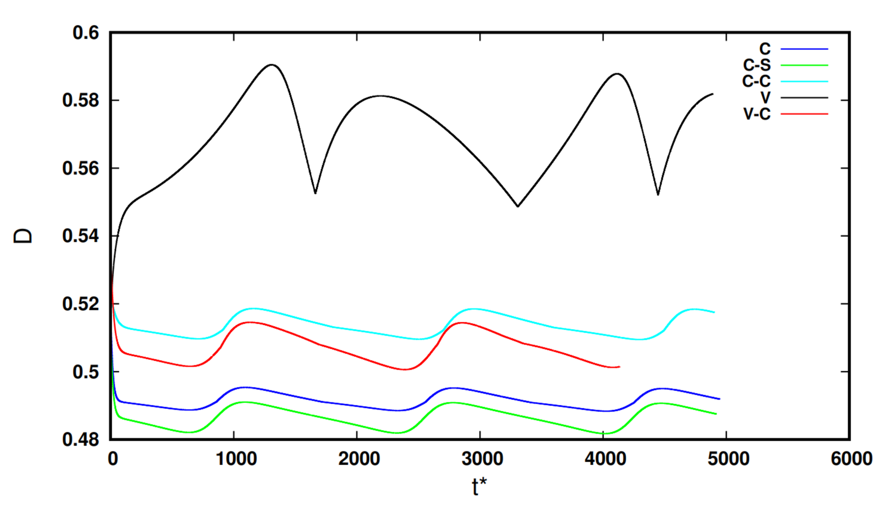


$$Ca = \eta_{ext} R\dot{\gamma}/\mu \quad , \quad \lambda = \eta_{int}/\eta_{ext}$$

Tumbling (Ca = 0.005, λ = 6.67) :

$$From\ Jeffery's\ theory, \quad r\tan\theta = \tan\frac{\dot{\gamma}t}{r + r^{-1}}$$

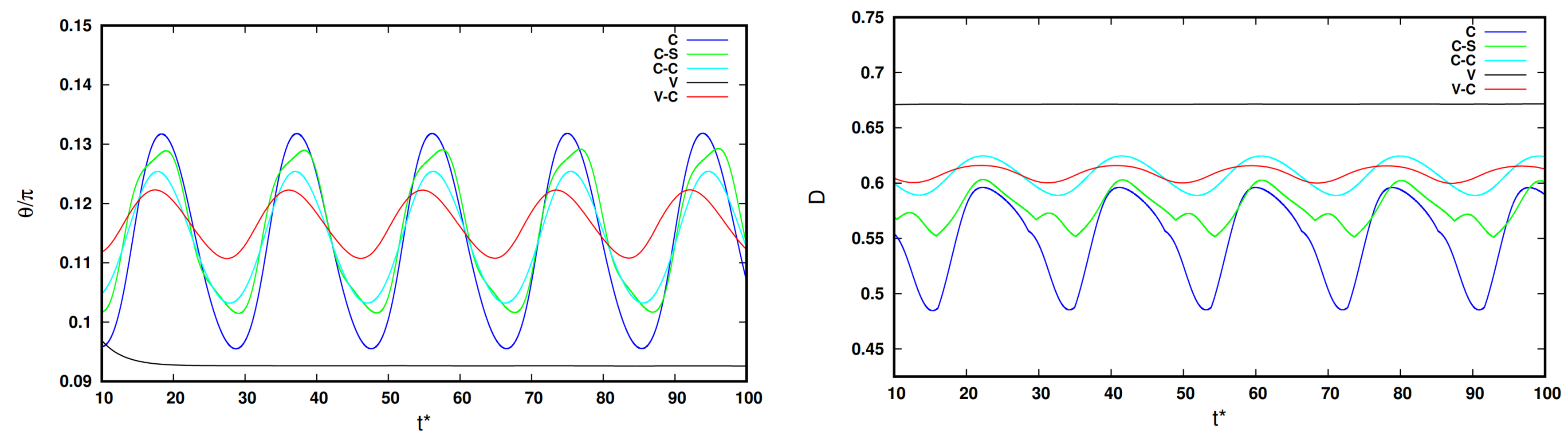


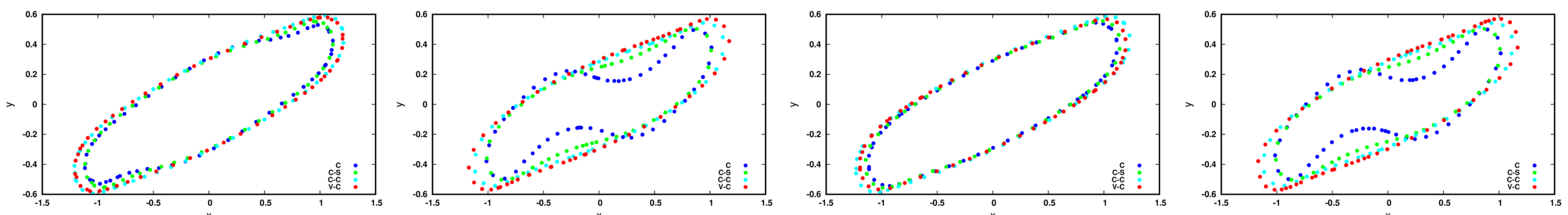


❖Different models follows different Jeffery's orbits.

Email : varun.puthumana@univ-amu.fr
ORCiD : 0000-0002-4371-5829
https://centuri-livingsystems.org/v-puthumana/

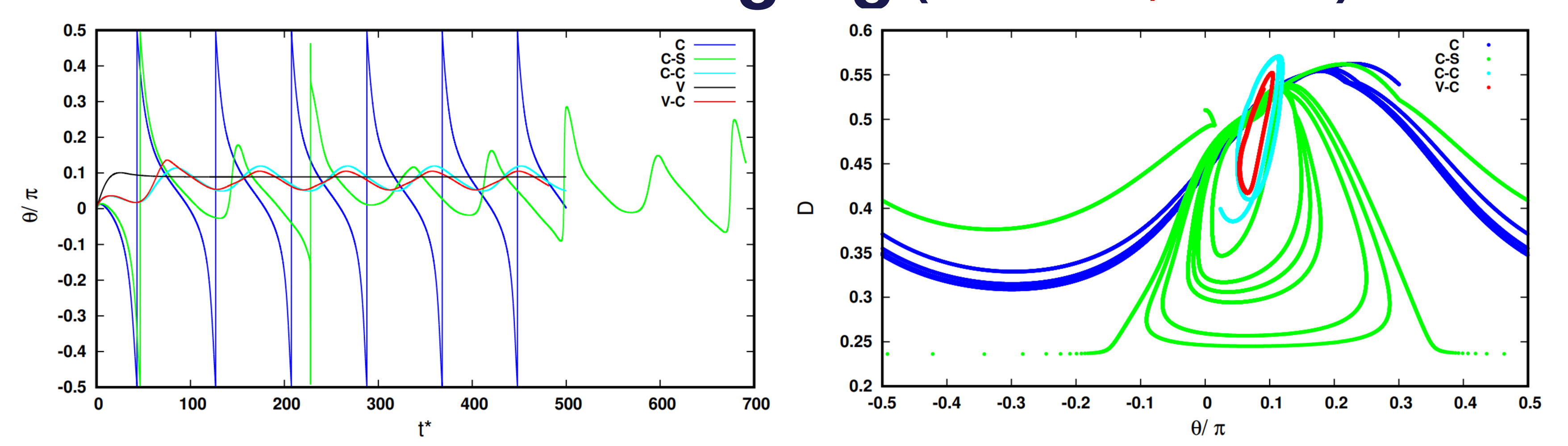
Swinging (Ca = 0.5, λ = 0.4) :



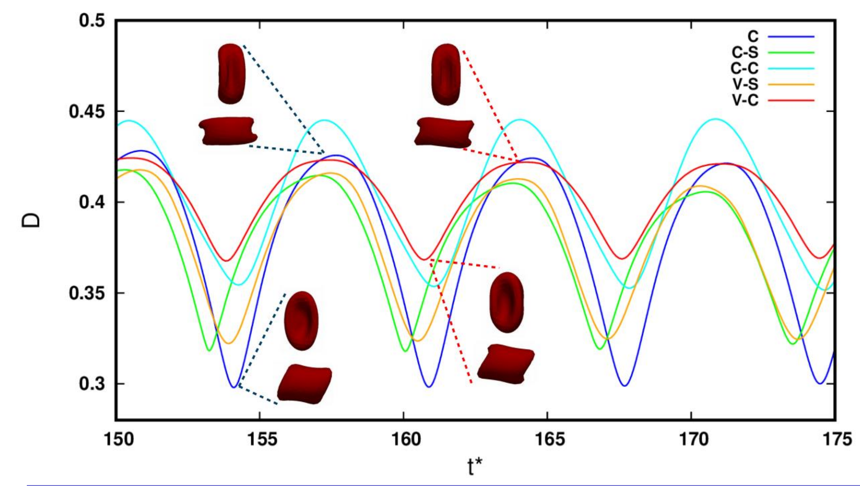


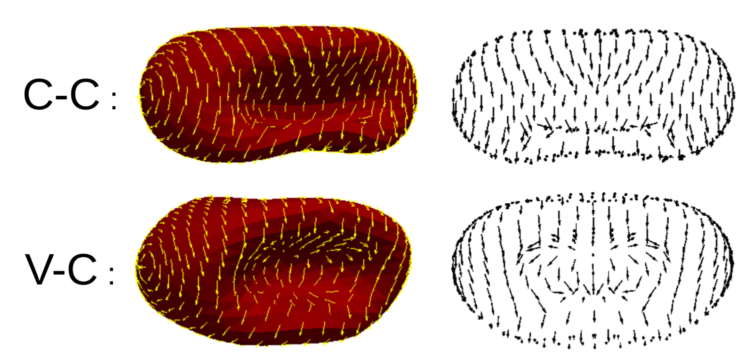
t* = 7   t* = 15   t* = 20   t* = 33

Transition to Swinging (Ca = 0.113, λ = 0.42) :



Multilobes (Ca = 1.5, λ = 6.67) :





Conclusion[3]

- Precise quantification shows that the deviation of modelling RBC as a Capsule is not so negligible.
- Accurate modelling strategy is at least as important as the choice of the stress free shape.
- Along with accurate mechanical membrane properties, the way they combine is also important as well.
- The anisotropy developed by the spring network made the V-S model unstable.

References

1. Barthès-Biesel, D. et al. J. Fluid Mech. 113:251–267, 1981
2. Boedec, G. et al. J. Comp. Phy. 342:117-138, 2017
3. Puthumana, V. et al. arXiv:2209.02328 [physics.flu-dyn]
4. Minetti, C. et al. J. Fluid Mech. 864:408-448, 2019
5. Mauer, J. et al. Phys. Rev. Lett. 121, 118103, 2018
6. Agarwal, D. et al. arXiv:2111.14206 [cond-mat.soft]