Supporting Material for "Actin network growth under load"

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Critical radius for saltatory oil drops propelled by actin comet tails

We provide here an example of the instability described in the main text and explain the experimental observations quantitatively.

In the last decade, Listeria-like propulsion has been extensively studied as a model system to understand the forces generated by growing actin networks. Actin-based propulsion of synthetic beads in cell extracts and also reconstituted systems helped elucidating the necessary and sufficient components for actin-based motility [1, 2]. While synthetic beads provide a good experimental system to study the effect of biochemical changes on macroscopic parameters of actin-based motility, they do not allow the measurement of the forces that actin networks generate while growing. Force measurements were achieved by substituting the synthetic (rigid) beads for oil droplets [3, 4]. The deformation of the oil drop acts as a transducer of the forces that the actin network is applying on the surface of the drop. Although lipid vesicles have been used for similar purposes and similar qualitative results are obtained, it is not possible to properly quantify stresses with lipid vesicles because the surface tension is not well defined. Unlike lipid vesicles, oil droplets have a well defined surface tension that allows for a proper quantification of stresses.

In Ref. [4], Trichet and coworkers show that oil droplets propelled by actin comet tails display two dynamical regimes: steady motion or saltatory behavior. The authors report that only oil droplets below a certain radius show saltatory behavior, while above this radius all droplets move with steady motion. Saltatory droplets show a characteristic cycle: first they grow an actin network almost homogeneously around them. The actin comet tail starts growing more at one side of the drop and the droplet gets increasingly deformed under the action of the forces generated by the growing actin network. The drop develops a pear-like (or kiwi-like) shape, with the actin network pushing and squeezing the drop along its sides and pulling it backward at its back. The largest stresses on the surface of the drop are the pulling stresses at its back [3, 4]. At some point, the drop losses contact with the actin network at its rearmost region, leading to a sudden forward jump and the relaxation of the deformation towards an undeformed spherical drop. The cycle in then started again, leading to a saltatory motion based on a slow droplet deformation and a fast relaxation caused by the loss of contact between the actin network and the drop at its rearmost region.

This saltatory instability based on the rupture of the contact between the actin comet tail and the back of the drop can be explained by the existence of a critical pulling stress above which network growth cannot be sustained. We now explain the observations described above within the framework developed in the main text. The characteristic scale of normal stresses σ_{nn} required to slightly deform an oil droplet of radius R and surface tension γ is

$$\sigma_{nn} \sim \frac{2\gamma}{R} \ . \tag{1}$$

These stresses correspond to the stresses applied on the actin network growing from the surface of a deformed drop. While the drop deformation is such that the actin network receives pushing stresses along the sides of the drop, at the back of the drop the actin network is pulled [3, 4]. The existence of a critical pulling stress σ_{nn}^c (explained in the main text) implies, from Eq. 1, the existence of a critical drop radius, R_c, which at scaling level reads

$$R_c \sim \frac{2\gamma}{\sigma_{nn}^c} \ . \tag{2}$$

Oil drops with radii below this critical value should display a rupture of the contact with the actin network, as can be seen from Eq. 1: the smaller the radius, the larger the stresses, meaning that the existence of a critical stress above which the drop losses contact with the network translates into a critical radius below which the drops display the instability. The loss of contact between the actin network and the drop should occur in the region where the pulling stresses are largest. Indeed, in Ref. [4] the authors report a critical drop radius above which no droplets are saltatory and they observe that the drop and the actin network lose their contact at the rearmost region of the drop, where the pulling stresses are maximal. Moreover, the authors in Ref. [4] measure both the surface tension of drops and the pulling stress at the back of a drop just before the instability occurs to be, respectively, $\gamma \simeq 4\text{nN}/\mu\text{m}$ and $\sigma_{nn} \simeq 1.5\text{nN}/\mu\text{m}^2$. Identifying the measured value of the stress at the back of the drop with the critical stress σ_{nn}^c (as it is measured just before the instability occurs), and using Eq. 2 we obtain a critical radius of $R_C \simeq 5.3\,\mu\text{m}$, which is reasonably close to the measured value of about $6\,\mu$m above which no saltatory movement is observed [4]. We recall that the calculations above are done at scaling level.

References

[1] Loisel TP, Boujemaa R, Pantaloni D, Carlier MF (1999). Reconstitution of actin-based motility of Listeria and Shigella using pure proteins. *Nature* 401:613-616.

[2] Upadhyaya A, van Oudenaarden A (2003). Biomimetic systems for studying actin-based motility. *Curr Biol* 13:R73444.

[3] Boukellal H, Campas O, Joanny J, Prost J, Sykes C (2004) Soft Listeria: Actin-based propulsion of liquid drops. *Phys Rev E Stat Nonlin Soft Matter Phys* 69:061906.

[4] Trichet L, Campas O, Sykes C, Plastino J (2007) VASP governs actin dynamics by modulating filament anchoring. *Biophys J* 92:1081-9.