Mechanical characterization of thin elastic membranes: cell mechanics applications

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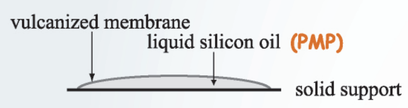
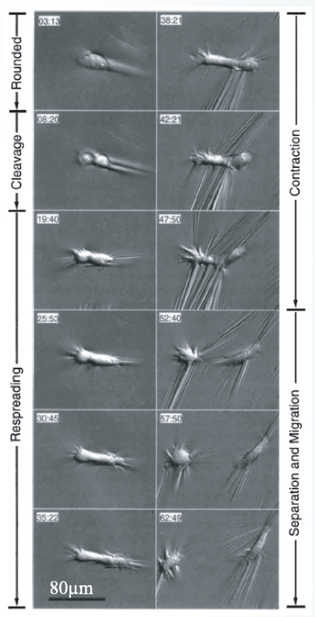
1. Wrinkling in elastic films

Membranes under study:

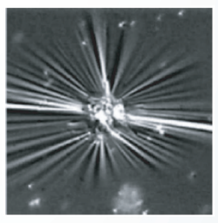


Synthesis protocol:

Some applications to Biomechanics:



Traction forces of cytokinesis measured with optically modified elastic substrata
[Burton & Taylor1997]

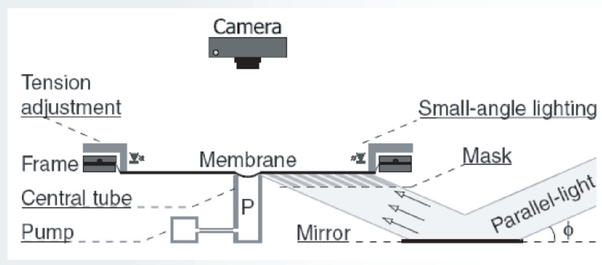


Radial contraction of a dying fibroblastic cell (fibroblast: migrates and proliferates readily in wound repair and in tissue culture).

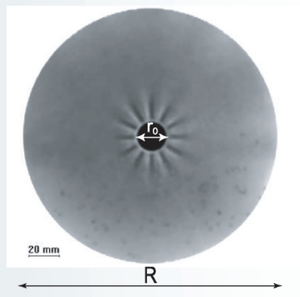
Can we use this tool to measure those forces quantitatively ?

2. Preliminary study on macroscopic membranes

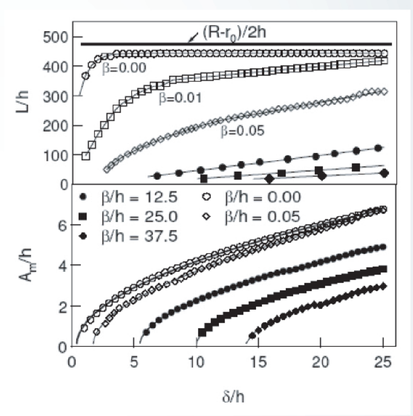
Experimental set-up:



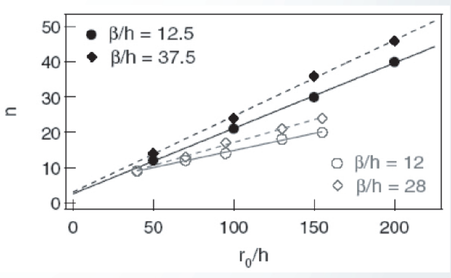
Top view of a buckling membrane:



Results:



L: wrinkle length
δ: imposed displacement
A_m: wrinkle amplitude
β: membrane tension
h: membrane thickness
n: number of wrinkles



Wrinkles formation in axi-symetrically stretched membranes
[Géminard, Bernal & Melo, 2004]

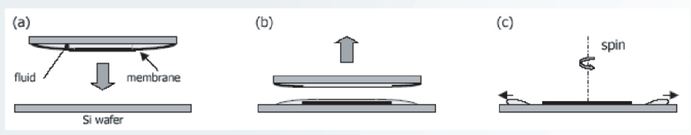
Conclusions

- ✓ Increase of both length and amplitude of wrinkles beyond a critical value function of membrane tension
- ✓ Number of wrinkles independent of applied force, varies slowly with membrane tension and linearly with size of deforming object
- ✓ Wrinkles length and **amplitude** very sensitive to membrane tension

3. Back to vulcanized membranes: measurements of relevant quantities

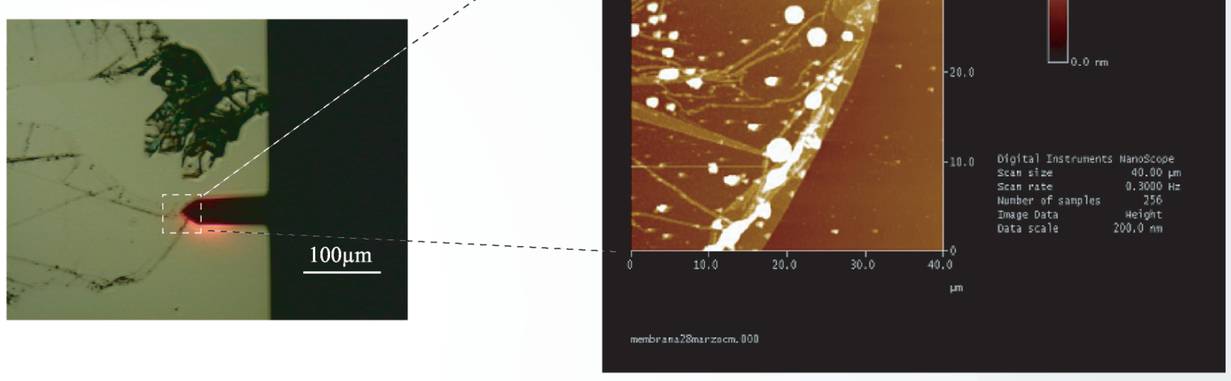
a- Membrane thickness by atomic force microscopy (AFM):

Samples preparation:



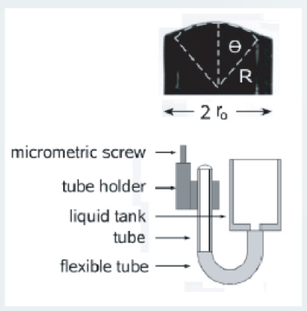
We measure h = 20 ± 5 nm

Deposition results and thickness measurements:

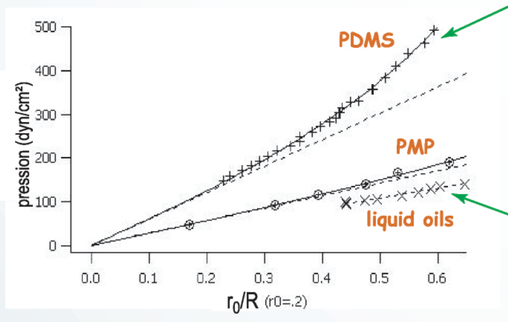


b- Elastic modulus (B) and membrane tension (T_0) by capillary type technique:

Experimental set-up:



Results:



Numerically-determined non-linear law in presence of a membrane:

$$\Delta P \approx 2T_0C + 2.66B\frac{\arcsin(Cr_0) - Cr_0}{r_0}.$$

C: curvature (1/R)

Laplace law:

$\Delta P = 2\gamma/R$, γ: surface tension

We get:

B = 240 ± 10 mN/m
T_0 = 60.5 ± 0.5 mN/m } (PDMS)

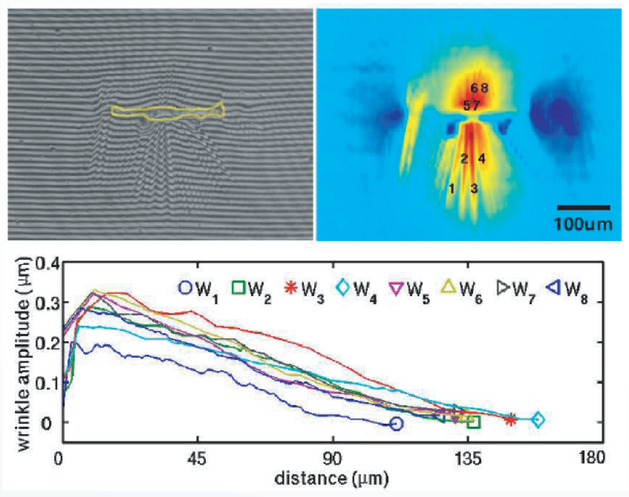
B = 20 ± 10 mN/m
T_0 = 27± 1 mN/m } (PMP)

4. About quantitative force measurements. Illustration with a fibroblastic cell

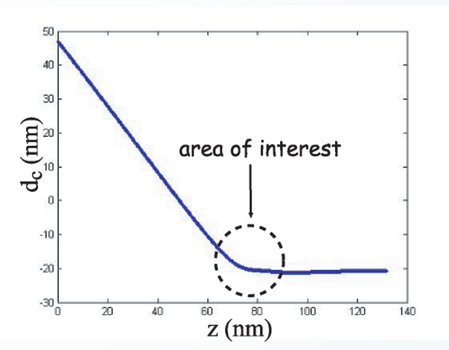
To make the relation between the wrinkle pattern and the local force, we need:

- to know the wrinkles amplitude A_m
- to have access to T_0 (dependent on membrane preparation)

Wrinkles amplitude: an interferometric method



Measure of T_0: from AFM force curves



From numeric simulations, we expect the force-displacement relation F(δ) to be:

$$F \approx \xi B^{1-\nu} T_0^{\nu} \delta$$

with: ξ= 1.143 ± 0.002
and ν= 0.881 ± 0.003

z: AFM tip displacement (from which we deduce indentation depth δ)
d_c: AFM cantilever deflexion (gives us the force: $F=k_c.d_c$)

IV Jornada CIMAT, Reñaca, Chile (2006)