Non-equilibration of hydrostatic pressure in blebbing cells

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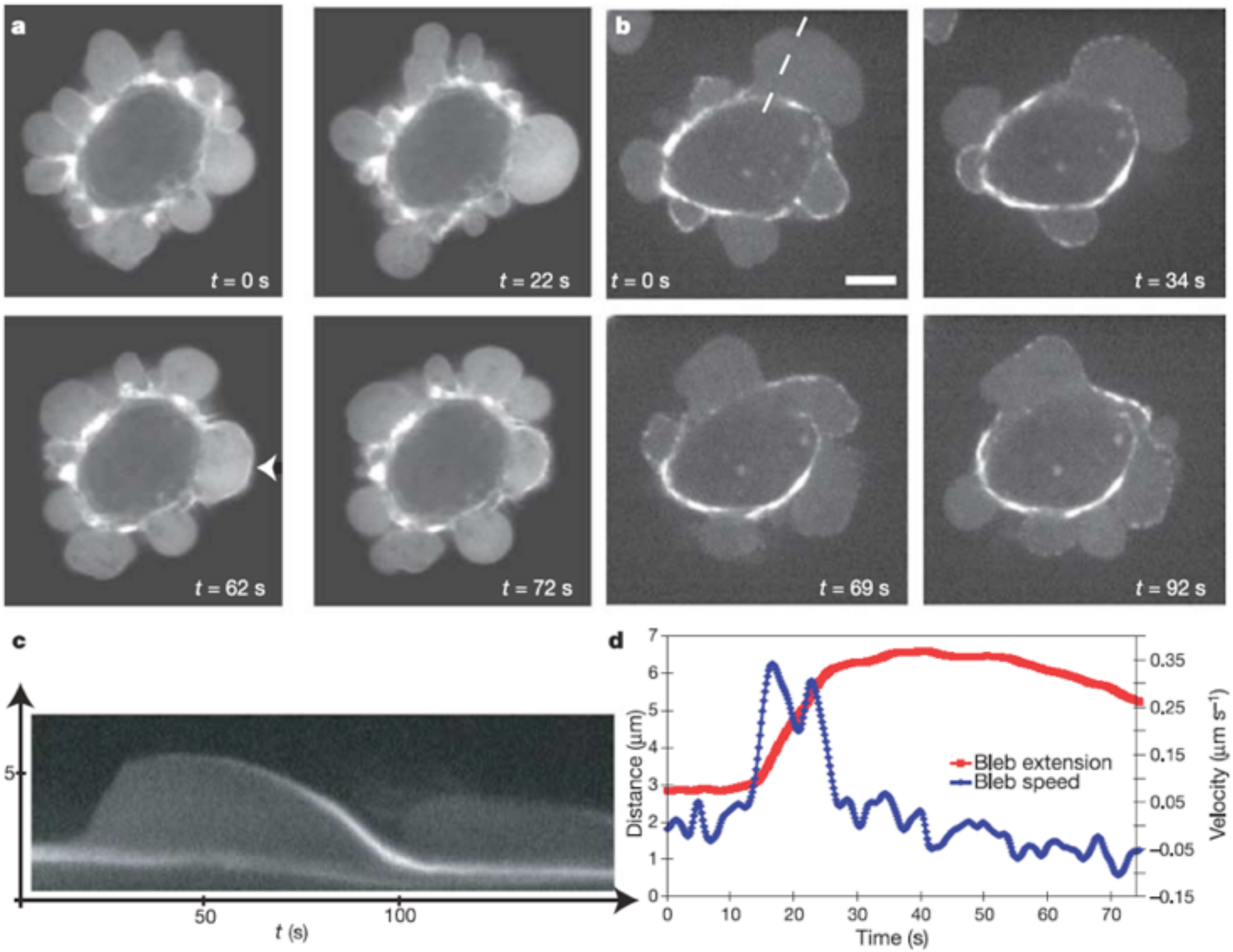
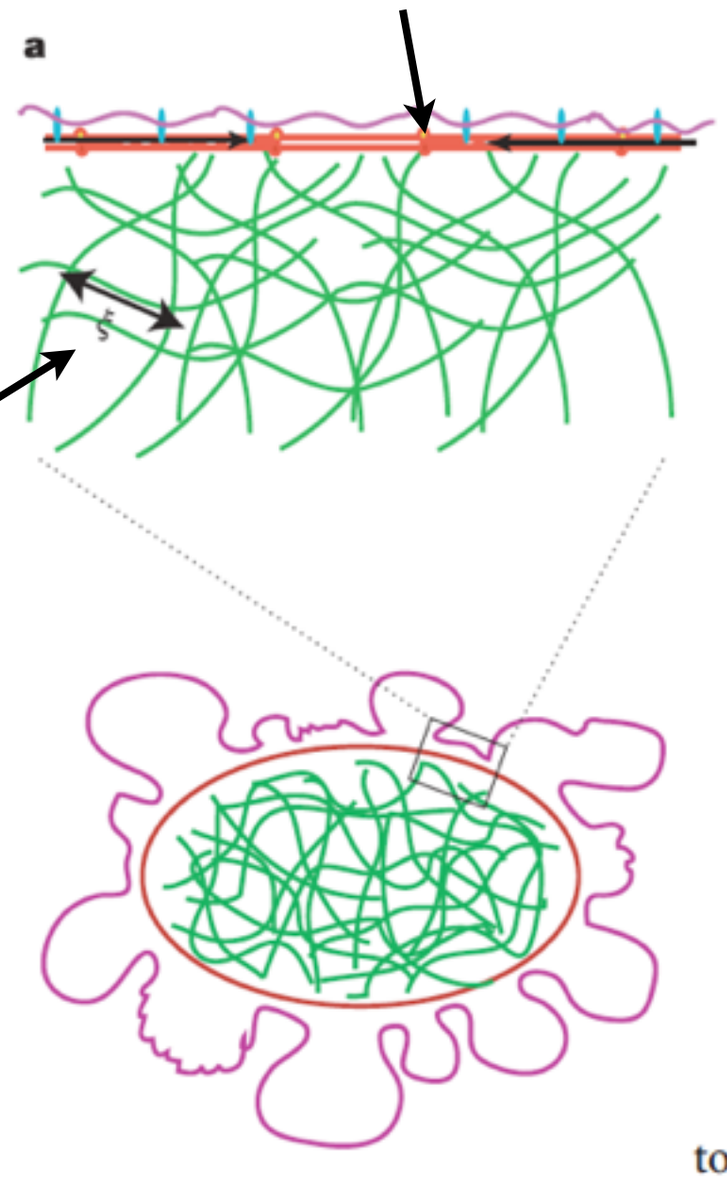
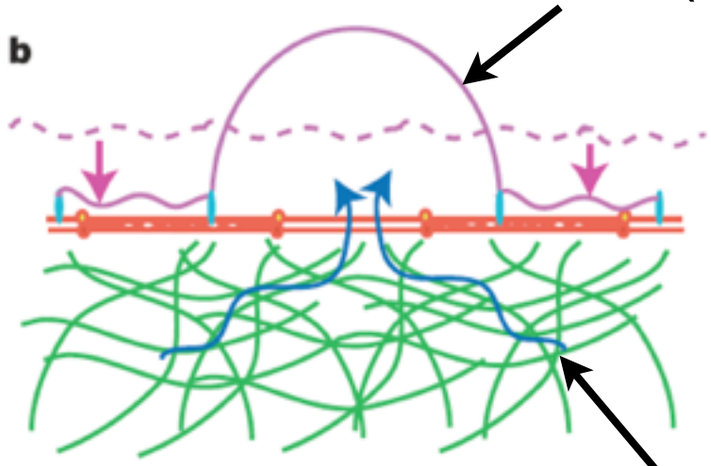
Vol 435|19 May 2005|doi:10.1038/nature03550



cortical acto-myosin contraction

bleb forms (rupture event)





pore-size or
mesh-size

fluid flows
through pores due
to hydrostatic pressure

together with drug studies discussed below, support the following qualitative model for bleb dynamics[19]. Cortical acto-myosin contracts (Supplementary Videos 10 and 11), generating hydrostatic pressure that causes a patch of plasma membrane to tear free from its attachment to the cortical cytoskeleton. This patch of cytoskeleton-free membrane rapidly inflates as cytosol flows in, with its base enlarging by further tearing (Supplementary Fig. 3). Later, inflation slows and a mesh of actin and myosin II assembles in the bleb to form a contractile cortex attached to the plasma membrane (Fig. 1b). Finally, contraction of this cortical mesh causes the bleb to shrink, driving the extruded cytosol back into the cell body.

Figures 7.14 and 7.15 removed due to copyright restrictions.
Source: Grodzinsky, Alan. Field, Forces and Flows in Biological Systems. Garland Science, 2011.

Fields, Forces, & Flows, Figures 7.14 & 7.15

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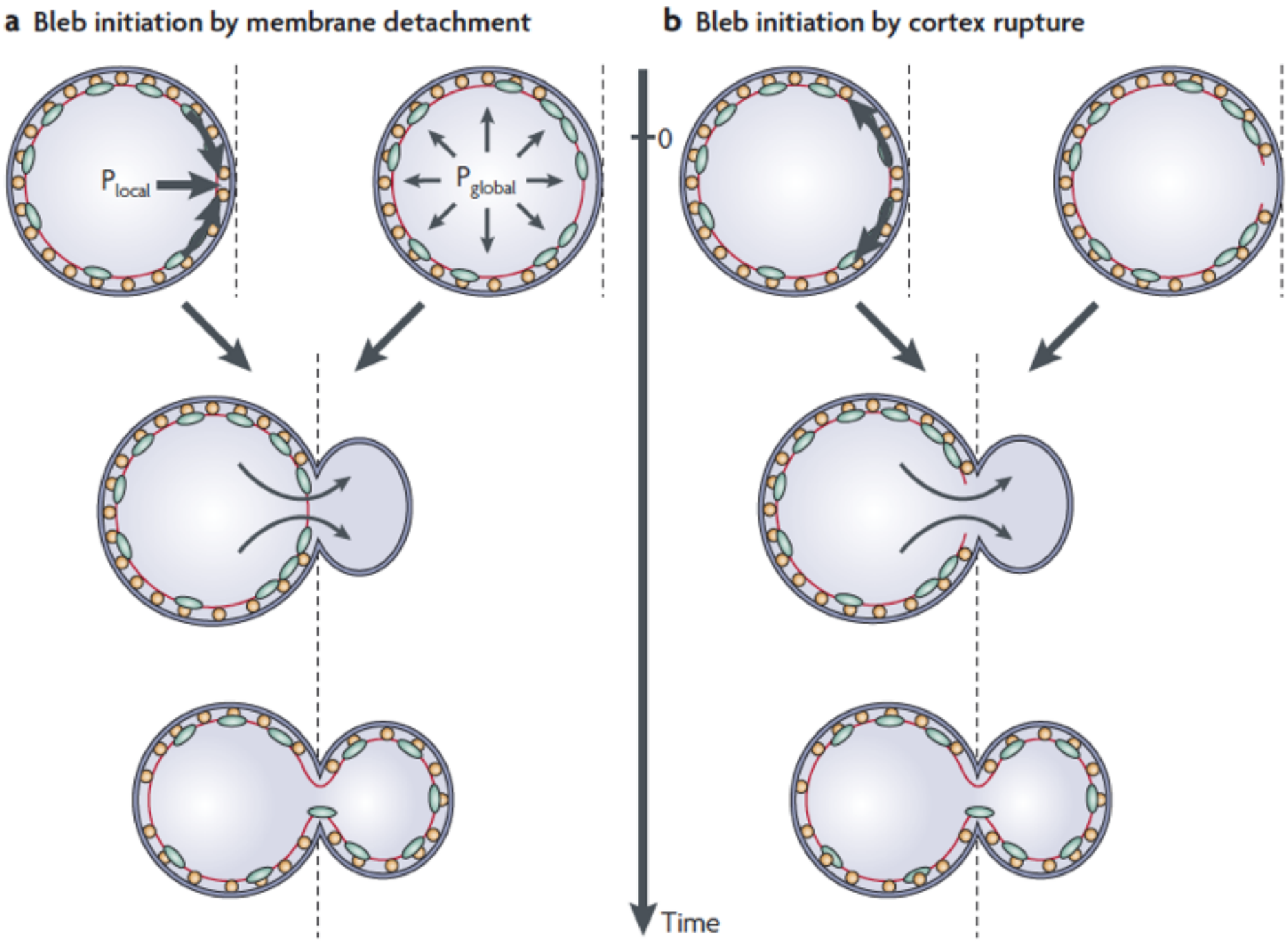
Source: Grodzinsky, Alan. Field, Forces and Flows in Biological Systems. Garland Science, 2011.

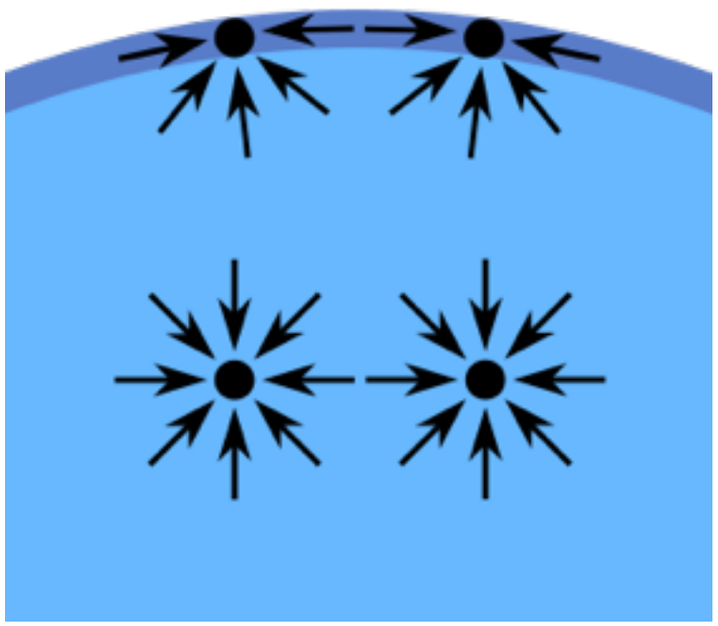
Cortical Actomyosin: “Surface Tension”



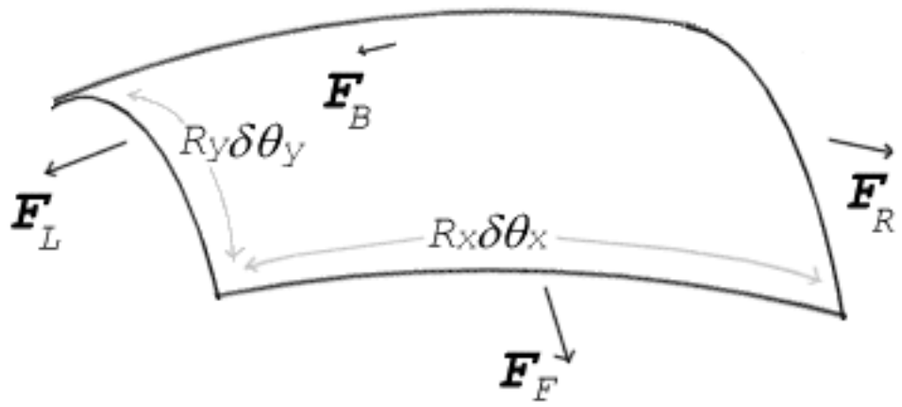
Charras & Paluch, *NatRev MCB* 2008

Cortical Actomyosin: “Surface Tension”

$$\Delta p = \gamma \left(\frac{1}{R_x} + \frac{1}{R_y} \right)$$

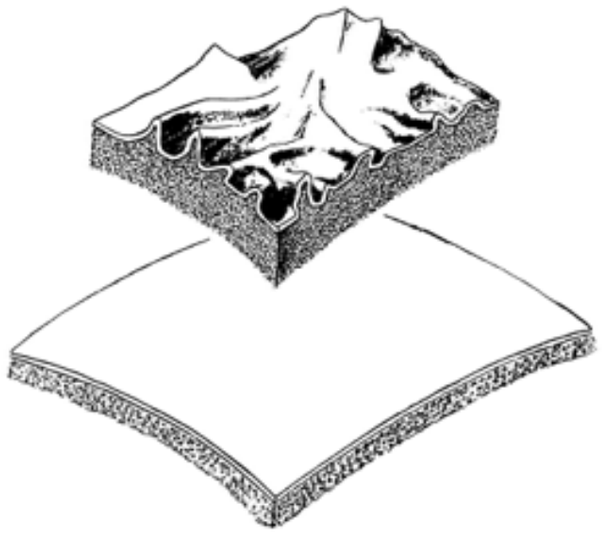


$$\gamma = \left(\frac{\partial G}{\partial A} \right)_{T,P,n}$$



$$\gamma = 1 \ \frac{dyn}{cm} = 1 \ \frac{erg}{cm^2} = 0.001 \ \frac{N}{m} = 0.001 \ \frac{J}{m^2}$$

Neutrophils behave like Newtonian fluids with surface tension:



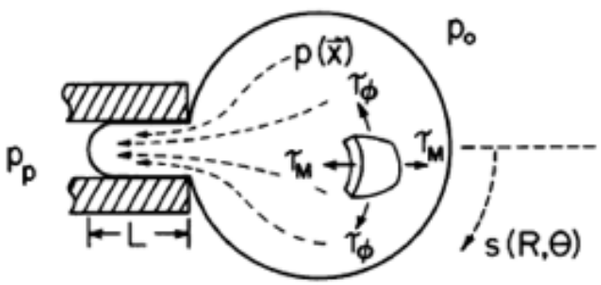


FIGURE 3 Schematic of the convergent flow into the pipet and the in-plane stress resultants supported by the cortical shell.

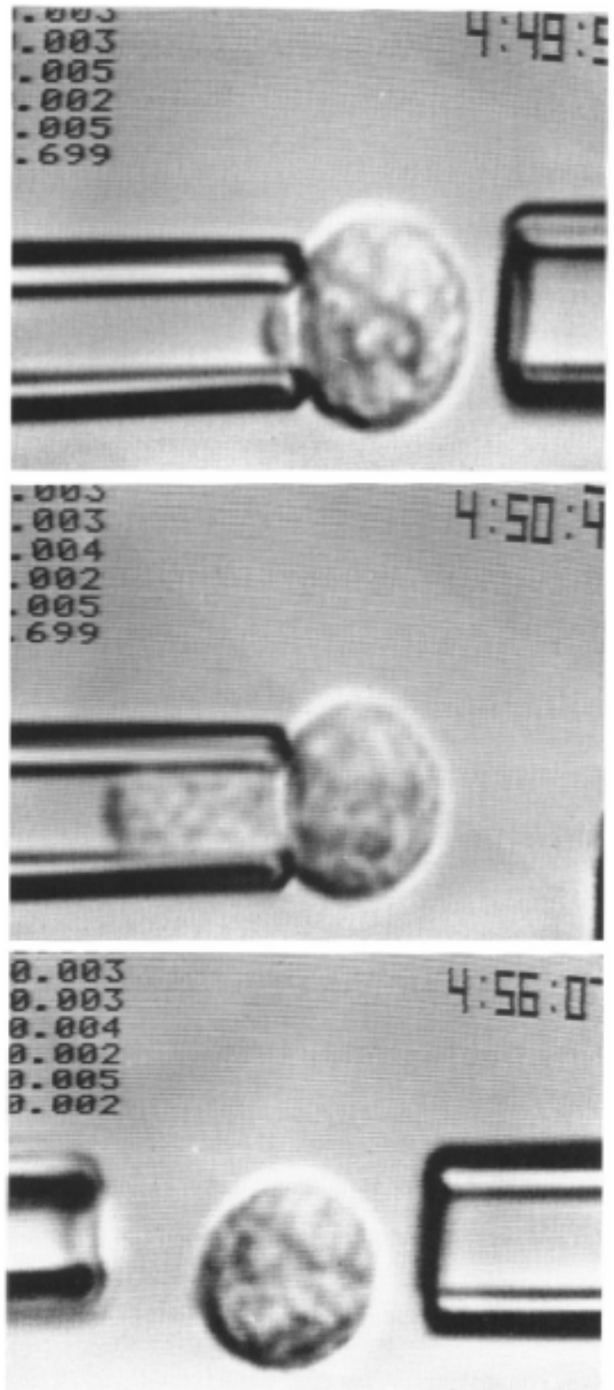


FIGURE 1 Sequence of video micrographs of a blood granulocyte aspirated into a 3.5 μm caliber pipet: (*a*) first, formation of a hemispherical cap at the threshold pressure with no further flow; (*b*) next, the extent of flow after the suction was elevated above the threshold for a fixed time period then returned to the threshold value; and (*c*) recovery of the cell to its initial spherical form after release from the pipet.

Evans & Yeung *Biophys J* 1989

Neutrophils behave like Newtonian fluids with surface tension:

Critical pressure for hemispherical cap:

$$P_{cr} = 2\bar{\tau}_o(1/R_P - 1/R_c)$$

Varying pipette radius:

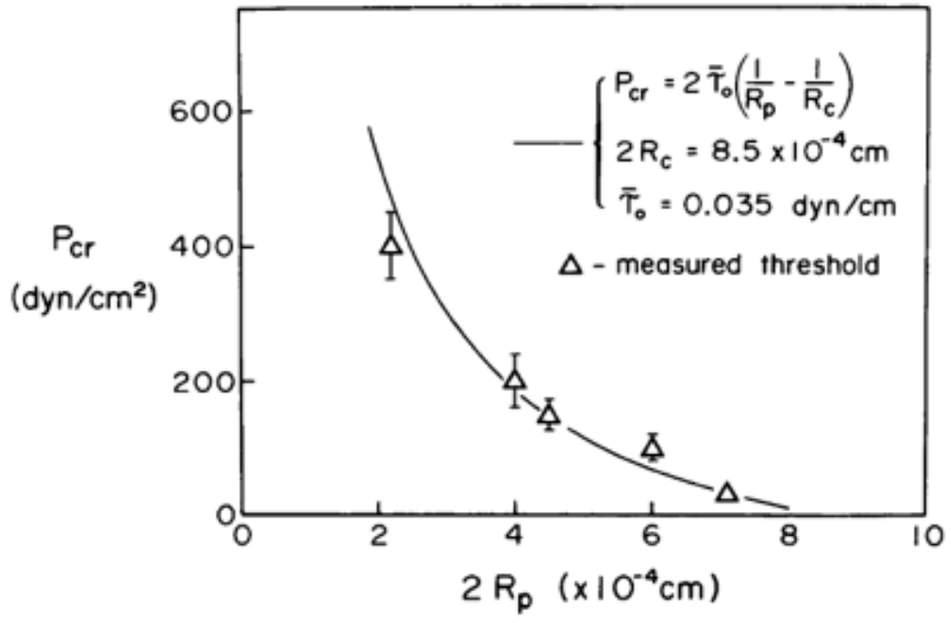


FIGURE 2. Threshold pressures required to form initial hemispherical projections inside pipets without further flow versus pipet radii. The solid curve is the theoretical correlation based on the presence of a persistent tension $\bar{\tau}_o = 0.035$ dyn/cm in the cell cortex. The average cell diameter was measured to be 8.5 μm.

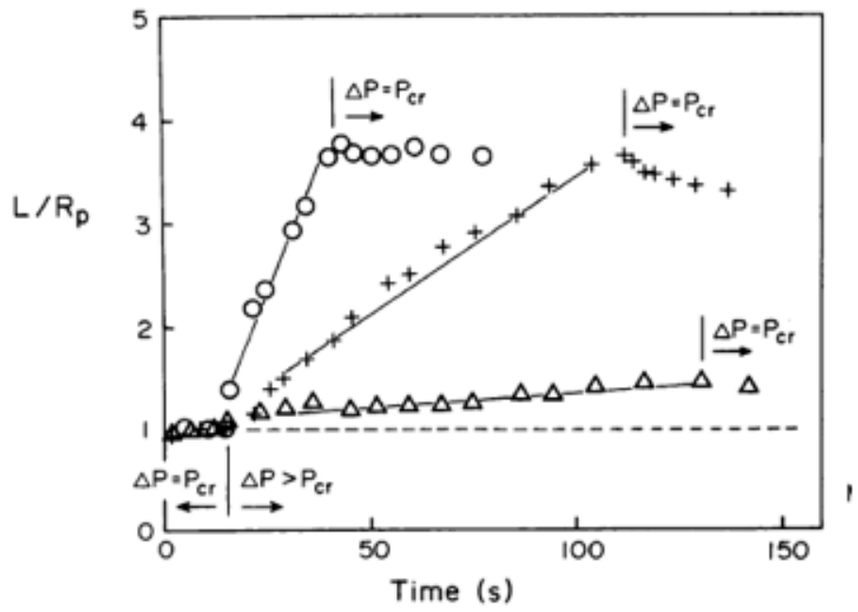
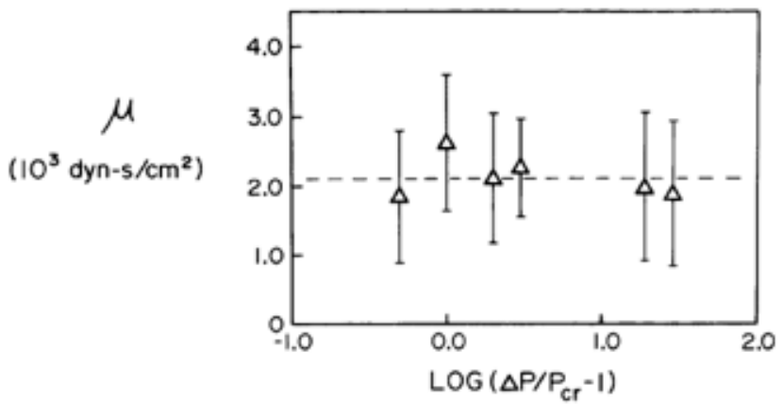


FIGURE 4. Measurements of projection length versus time for a single granulocyte subjected to three aspiration tests with a medium-size pipet where suction pressure was varied between 1.5–4.3 times the threshold value. This figure illustrates the proportional increase in entry flow rate with excess pressure above the threshold value.



Chondrocytes are more like elastic spheres

Table 1
"Natural" SI units at the level of the cell

	"Micro SI"	Application
Distance (m)	1 μm (10^{-6} m)	All
Force (N)	1 pN(10^{-12} N)	Molecular bonds "soft" cells
	1 nN(10^{-9} N)	Stiff cells
Pressure, stress (Pa)	1 pN/μm^2(1 Pa)	Soft cells (blood cells)
	1 nN/μm^2(1 kPa)	Stiff cells
Tension (mN/m)	1 pN/μm (10^{-3} mN/m)	Cortical elasticity of soft cells
	1 nN/μm(1 mN/m)	Elasticity of lipid bilayer

Hochmuth *J Biomech* 2000

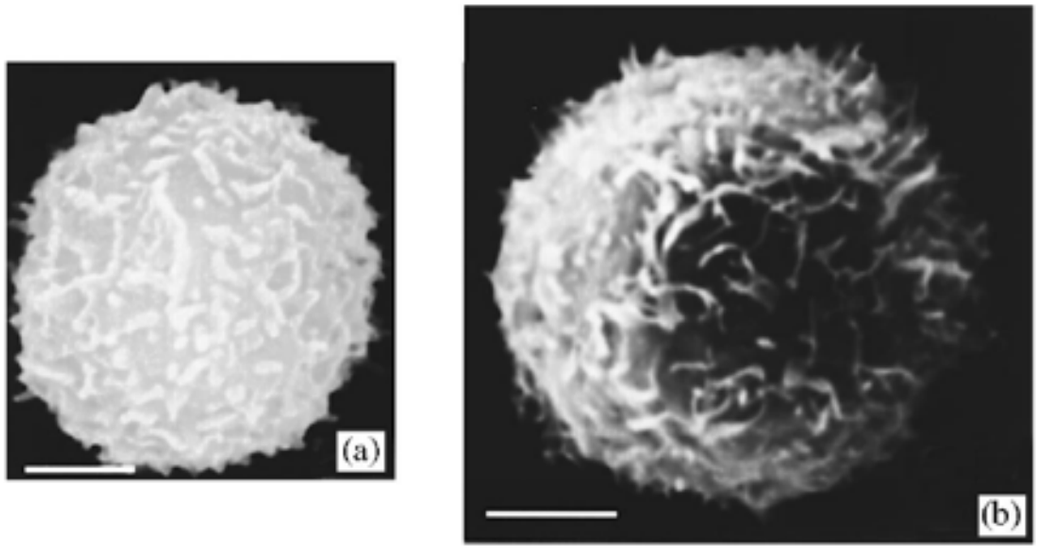


Fig. 3. Comparison of a human neutrophil (a) to a chondrocyte (b). The neutrophil has a diameter of about 8 μm while the majority of chondrocytes have diameters between about 12 and 16 μm. The scale bars indicate 2 μm, but note that the significant shrinkage of the cell has occurred during the preparation of the cells for scanning electron microscopy.

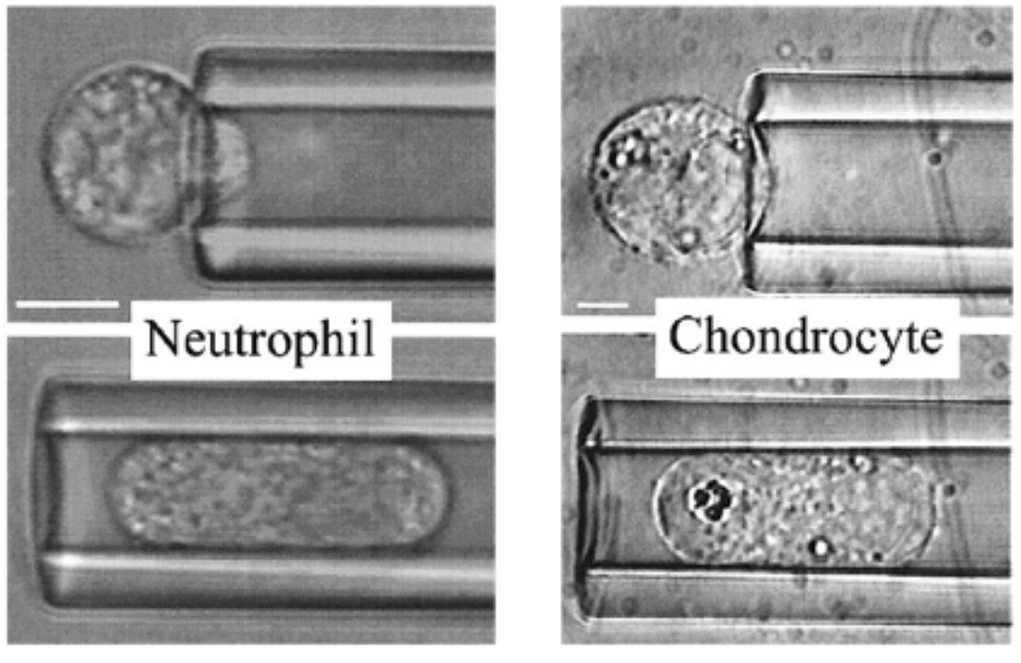


Fig. 4. A neutrophil and a chondrocyte each being aspirated into a micropipette. The photomicrographs of the chondrocyte are adapted from Jones et al. (1999). The scale bars indicate 5 μm.

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Fall 2015