Capillary Micromechanics
Probing gel particles, spheroids and tissue

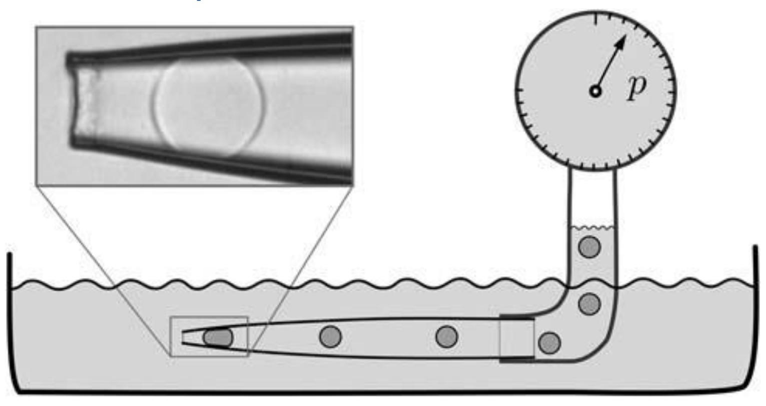
A. Link, T. Franke

Division of Biomedical Engineering, University of Glasgow, Glasgow, UK
E-mail: thomas.franke@glasgow.ac.uk

Abstract: We classify native and chemically modified red blood cells with an AI based image and video classifier. Using TensorFlow video analysis enables us to capture not only the morphology of the cell but also the trajectories of motion of individual red blood cells and their dynamics. We chemically modify cells in three different ways to model different pathological conditions and obtain classification accuracies for all three classification tasks of more than 90% between native and modified cells. Unlike standard cytometers that are based on immunophenotyping our microfluidic cytometer allows to rapidly categorize cells without any fluorescence labels simply by analysing the shape and flow of red blood cells.

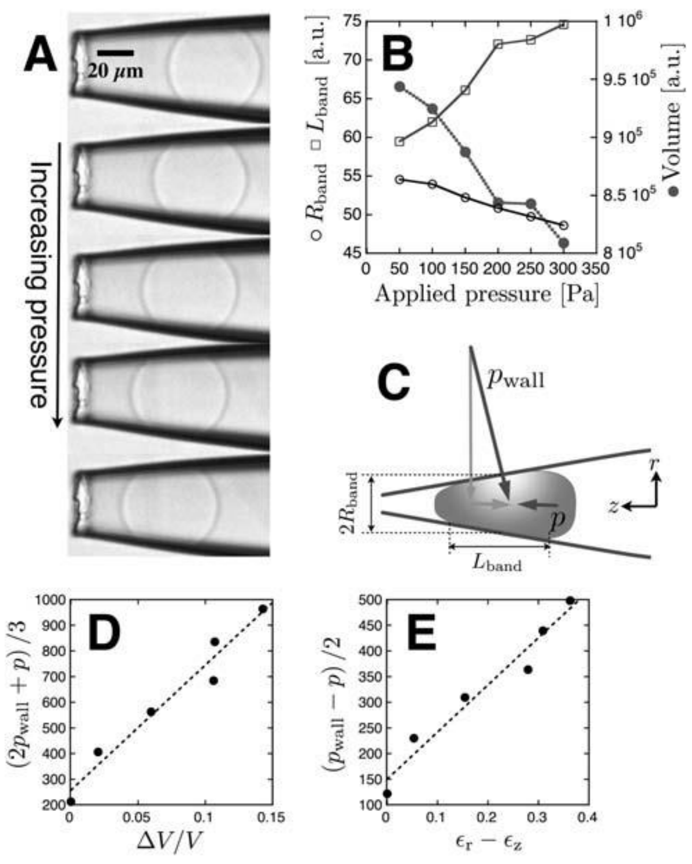
Capillary Micromechanics Method

A dilute suspensions of soft particles flows towards the tapered tip of a microcapillary as a result of an applied pressure difference. Pressures can be adjusted by connecting the sample reservoir to a pressure regulator. As a single particle blocks the flow of fluid, the particle deforms until the pressure-induced external stresses are balanced by its internal elastic stress. The pressure-dependence of the shape and size of the particle is thus a direct measure of its elastic properties.



PAM gel particles

(A) Microgel particle being deformed as the applied pressure increases (B) Change of the particle geometry. The contact area where the particle surface is in contact with the glass wall has the shape of a tapered band, with average radius R_{band} and width L_{band}. As the applied pressure p increases, R_{band} (open circles) decreases and L_{band} (open squares) increases. The volume of the particle decreases, indicating that the particle has a finite compressive modulus.



(C) Schematic of deformation: z-component of contact forces balance the applied pressure. (D) Compressive stress as a function of the volumetric strain; the dashed line is a linear fit to the data; the compressive modulus of the particle is given by the slope of this curve, K=4.5 kPa. (E) Differential stress $(p_{wall} - p)/2$ as a function of (ε_r- ε_z); the elastic shear modulus is the slope of the linear fit curve, G = 0.8 kPa.

Moduli

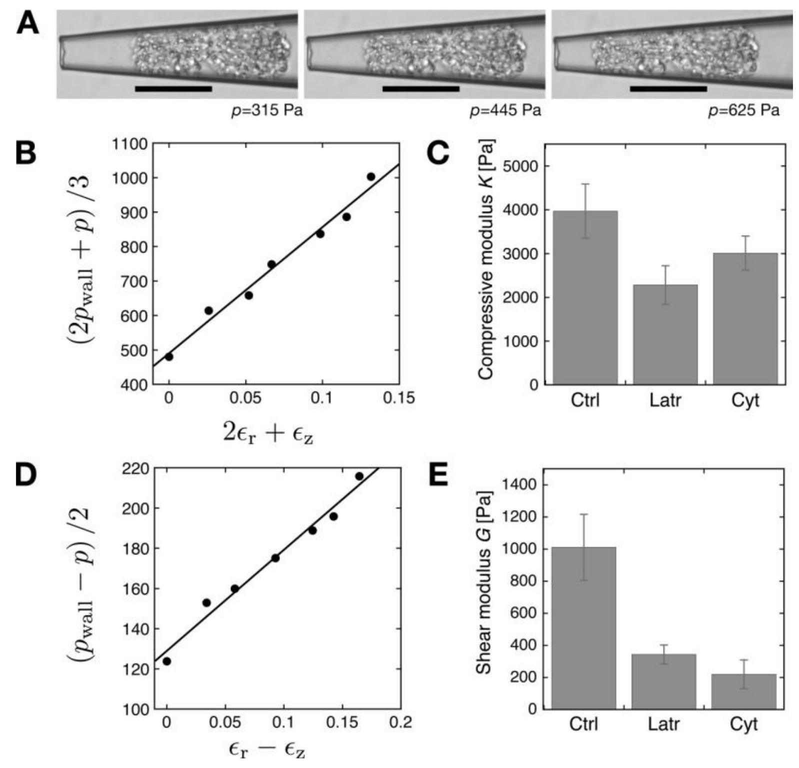
$$K = \frac{\frac{1}{3}(2p_{wall} + p)}{2\varepsilon_r + \varepsilon_Z} \qquad (1)$$

$$G = \frac{\frac{1}{2}(p_{wall} - p)}{\varepsilon_r - \varepsilon_Z} \qquad (2)$$

$$E = \frac{9KG}{3K + G'} \qquad (3)$$

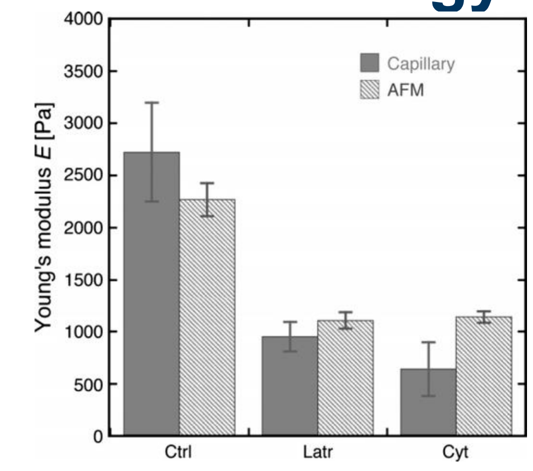
Glomeruli

Rat glomeruli were treated with Cyto D (5 M), Lat B (500 nM), or left untreated. A: microscope images of an untreated glomerulus deforming (scale bar 100μm). B: Plot of the stress relevant for compression versus the volumetric strain defor-mation. The slope of the line is the compressive modulus. C: average values of the compressive modulus for untreated glomeruli (n=4), for glomeruli treated with Cyto D (n=3), and Lat B (n=5); The values for cytochalasin- and latrunculin-treated glomeruli were different from control (P 0.05, ANOVA) but not from each other. D: plot of the stress relevant for shear deformation versus the relevant strain (ε_r- ε_z). Slope of the line is the shear modulus for the sample shown in A. E: average values of the shear modulus for untreated glomeruli (n=4) and glomeruli treated with Cyto D (n=3), and Lat B (n=5); the error bars represent the corresponding means SE. The values for cytochalasin and latrunculin treated glomeruli were different from control (P < 0.05, ANOVA) but not from each other.

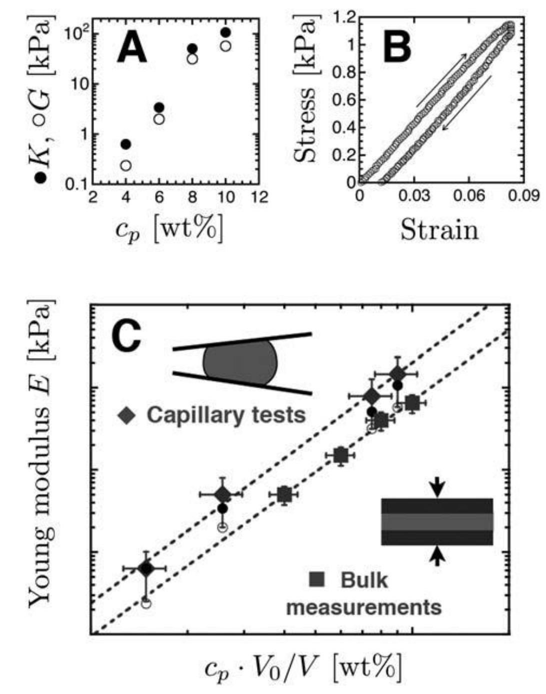


Comparison with AFM and bulk rheology

Comparison of Young’s modulus values obtained using atomic force microscopy and capillary micromechanics for untreated glomeruli and glomeruli treated with 5 M Cyto D and 500 nM Lat B. Dark bars represent capillary micromechanics data, and light bars represent AFM data.



(A) Compressive modulus K (solid circles) and shear modulus G (open circles) on polymer concentration cp. (B) Typical data from a bulk compressive mechanical test. The curve with 6% polymer concentration; the arrows indicate the order of data as the sample is compressed and then immediately decompressed again at a rate of 0.1 mm/min. (C) Young’s modulus E from compressive mechanical tests on bulk poly-acrylamide gels (squares) and for microgel particles (diamonds) as derived from the compressive modulus K (solid circles) and the shear modulus G (open circles).



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- Wyss HM, Henderson JM, Byfield FJ, et al. Biophysical properties of normal and diseased renal glomeruli. Am J Physiol Cell Physiol. 2010 Dec 1;300(3):C397-C405. https://doi.org/10.1152/ajpcell.00438.2010