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Measurement of cytoplasmic viscosity in neutrophils between 0.1 Hz and 300 Hz

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Cell deformability, motility, cytoplasmic streaming and intracellular particle transport depend critically on cytoplasmic viscosity. Large deformation micropipette aspiration studies on neutrophils reveal a moderate shear thinning with a power-law dependence of viscosity on the shear rate (exponent -0.52 ; Tsai MA et al., *Biophysical J* 1993; 65:2078-88). Actin and tubulin suspensions exhibit a stronger power-law behavior (exponent -1.0 ; Buxbaum RE et al., *Science* 1987;235:1511-14). We measured cytoplasmic viscosity using a novel technique: ferromagnetic beads (diameter $4.5 \mu\text{m}$) coated with anti-CD45 antibodies were bound to rat neutrophils centrifuged onto a cell culture dish. The beads were magnetically twisted with a sinusoidal field of 35 Gauss between 0.1 and 300 Hz. The resulting bead displacement ($<200 \text{ nm}$ at 0.1 Hz) was recorded with a phase-locked video camera. From 0.1-10 Hz, we found a power-law behavior of viscosity vs. shear rate with exponent -0.99 ± 0.01 (mean \pm SE, $n=39$), strikingly similar to Buxbaum's findings in actin and tubulin networks. At higher frequencies, viscosity approached a constant value. An exponent around -1.0 has far-reaching consequences: the force required to deform the cell or to move intracellular particles is rate independent. This may promote shape stability at rest, while increasingly rapid mechanical events do not require increasingly larger forces.