Abstract Submitted
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Optimal ciliary beating patterns ANDREJ VILFAN, NATAN OSTERMAN, J. Stefan Institute, Ljubljana, Slovenia — We introduce a measure for energetic efficiency of single or collective biological cilia. We define the efficiency of a single cilium as Q^2/P, where Q is the volume flow rate of the pumped fluid and P is the dissipated power. For ciliary arrays, we define it as $(\rho Q)^2/(\rho P)$, with ρ denoting the surface density of cilia. We then numerically determine the optimal beating patterns according to this criterion. For a single cilium optimization leads to curly, somewhat counterintuitive patterns. But when looking at a densely ciliated surface, the optimal patterns become remarkably similar to what is observed in microorganisms like *Paramecium*. The optimal beating pattern then consists of a fast effective stroke and a slow sweeping recovery stroke. Metachronal waves lead to a significantly higher efficiency than synchronous beating. Efficiency also increases with an increasing density of cilia up to the point where crowding becomes a problem. We finally relate the pumping efficiency of cilia to the swimming efficiency of a spherical microorganism and show that the experimentally estimated efficiency of *Paramecium* is surprisingly close to the theoretically possible optimum.

[1] N. Osterman and A. Vilfan, Finding the ciliary beating pattern with optimal efficiency, Proc. Natl. Acad. Sci. USA, in press (2011)

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