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Collective hydrodynamics of swimming micro-organisms

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Since the work of Kessler in the 1980s, and before, there has been considerable interest among fluid dynamicists and physicists in the collective behaviour of swimming micro-organisms in suspension. Since all such cells are denser than the water in which they swim, bioconvection patterns result from upswimming of cells in a chamber of finite depth and from gyrotaxis of bottom-heavy cells in a uniform fluid. Bioconvection has been analysed for dilute suspensions; the theory will be briefly re-examined with emphasis on the additional stress induced by the cells' swimming motions (each cell can be regarded as a force-dipole, or stresslet), because of the new instabilities revealed by Simha & Ramaswamy (2002) for uniform suspensions in the absence of gravity. Even more fascinating coherent structures arise in concentrated suspensions, of bacteria for example, in which cell-cell interactions cannot be ignored. The hypothesis is that such structures emerge from purely hydrodynamic interactions between cells. A variety of models have been developed, which are outlined briefly, but particular attention will be paid to our own model in which cells are represented as inertia-free "spherical squirmers," whose behaviour is dominated by near-field hydrodynamics. Pairwise interactions are computed precisely, and Stokesian dynamics in a periodic box is used to simulate an infinite suspension. Trajectories are computed deterministically, but the long-time spreading of a 3D suspension, from random initial conditions, is diffusive; scaling arguments can be used to estimate the effective diffusivity. However, in 2D there is a strong tendency towards aggregation into clumps or bands. [Recent work reported here has been performed in collaboration with T Ishikawa and J T Locsei.]