Asymptotic Analysis of Quorum-Sensing Behavior for a Coupled Cell Bulk-Diffusion Model in 2-D

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We formulate and analyze a class of coupled cell-bulk PDE models in 2-D bounded domains. Our class of models, related to the study of quorum sensing, consists of m small cells with multi-component intracellular dynamics that are coupled together by a diffusion field that undergoes constant bulk decay. We assume that the cells can release a specific signaling molecule into the bulk region exterior to the cells, and that this secretion is regulated by both the extracellular concentration of the molecule together with its number density inside the cells. By first constructing the steady-state solution, and then studying the associated linear stability problem, we show for several specific cell kinetics that the communication between the small cells through the diffusive medium leads, in certain parameter regimes, to the triggering of synchronized oscillations that otherwise would not be present in the absence of any cell-bulk coupling. Moreover, in the well-mixed limit of very large bulk diffusion, we show that the coupled cell-bulk PDE-ODE model can be reduced to a finite dimensional system of nonlinear ODEs with global coupling, that exhibits quorum-sensing behavior, whereby a collective oscillation occurs only if the number of cells exceeds a threshold. The analytical and numerical study of these limiting ODEs reveals the existence of globally stable time-periodic solution branches that are intrinsically due to the cell-bulk coupling.

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