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Oxygen Transport Across Space-Filling Biological Membranes

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— Space-filling fractal surfaces play a fundamental role in how organisms function and in how structure determines function at various levels. In this project we developed an efficient and powerful algorithm, rope-walk algorithm, for solving diffusion equations of transport of species across the space-filling fractal surface. We performed analytic computations of the oxygen current across the alveolar membranes in the lung, as a function of diffusion coefficient and membrane permeability, using the rope-walk algorithm, without adjustable parameters. The analytic calculation identifies the four cases as sharply delineated screening regimes and finds that the lung operates in the partial-screening regime, close to the transition to no screening, and in the no-screening regime, for respiration at rest and in exercise respectively. The gas exchange satisfies six criteria of optimal design: maximum current; minimum waste of surface area; minimum permeability; maximum fault tolerance; minimum waiting time and maximum current increase when going from rest to exercise. This extraordinary, multiply optimized performance is a direct consequence of the space-filling membrane architecture.

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