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Multi-scale spatial heterogeneity enhances particle clearance in airway ciliary arrays[1] GUILLERMINA RAMIREZ-SAN JUAN, ARNOLD MATHIJSSEN, Stanford University, MU HE, LILY JAN, WALLACE MARSHALL, University of California San Francisco, MANU PRAKASH, Stanford University —
Mucus clearance is the primary defense of the respiratory system. This transport across the airway emerges from the integrated activity of thousands of cilia, which coordinate their spatial arrangement, alignment and motility. The mechanisms of fluid transport by cilia have been studied extensively at the level of the individual cilium and metachronal waves. However, how the topology of ciliary arrays is optimized to generate organ-scale directed flows is largely unexplored. Here, we image the mouse airway to map the geometry of its ciliary carpet, from the sub-cellular (10^{-9}m) to the organ scales (10^{-3}m), characterizing quantitatively its ciliary arrangement and the generated flows. Locally we measure heterogeneity in both cilia organization and flow structure, but across the trachea fluid transport is coherent. To examine this result, we develop a hydrodynamic model to explore systematically different tissue architectures. Surprisingly, we find that disorder enhances particle clearance, whether it originates from fluctuations, heterogeneity in multiciliated cell arrangement or ciliary misalignment. Together, our results shed light on how the microstructure of an active carpet determines its emergent dynamics and are applicable to understand airway pathologies.

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