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Diffusion-Convection Interaction As A Cause Of Uneven Gas Distribution In Rabbit Lung

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Rationale: Interaction between convection and diffusion has been suggested to play a crucial role in the uneven distribution of gases in the mammalian lung. Here we present the first direct experimental demonstration of this process in vivo. We quantitatively reproduced the experimental data using a computational model, by simulating convective and diffusive transport in a realistic lung morphometry.
Methods: The experiments were performed in 4 anesthetized and mechanically ventilated rabbits (2.9 ± 0.1 kg). We used K-edge subtraction synchrotron imaging (KES) to image the distribution of xenon in the airspaces at 350 µm resolution (1) at 1.15 s intervals during a slow Xe inhalation. The maximal airway pressure set at 30 cmH_2O was reached 30 s after the beginning of a slow Xe inhalation, and followed by a breath hold. Synchrotoron images of a rabbit right lung were segmented, and custom software was used to extract the branching structure of conducting airways (2). The resulting tree structure included 7175 branching airways, feeding 3843 terminal acinar units. We simulated gas transport in this structure using a previously described transport equation (3), and imposing at the model entrance, the Xe flows recorded during the imaging experiments (Figure 1-A, lower panel). For the numerical solution of the gas transport equation, the right lung structure was discretized into 933274 nodes. The transport equation was solved on all nodes between the model entrance and the acinar ends, where a boundary condition of reflection was imposed.
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Results: Figure1-A shows experimental Xe concentration vs. time in a representative image slice of the right lung; red curves are the Xe concentration and flow at the model entrance. Corresponding simulations (Figure1-B) show that very similar curves are obtained by solving the equation of diffusive and convective gas transport (3) in the bronchial tree structure, without any parameter fitting. The most relevant agreement between experiments and simulations concerns the relative standard deviation of peripheral Xe concentration (RSD(Xe)). Both the degree of Xe concentration heterogeneity during inhalation and it's very slow equilibration during breath hold, are the direct result of the diffusion-convection interdependence.
Conclusions: These data provide the first in vivo demonstration of the diffusion-convection interaction concept in the mammalian lung. The rabbit lung, with its asymmetrical branching pattern and wide dispersion of acini across airway generations, allowed the in situ observation of gas distribution heterogeneity.

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