The fluid structure interaction in a highly hierarchical structure: the lung airway system

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The lung airway system in humans is a complex branched distribution system whose structure exhibits highly hierarchical features and scale invariance. Ideally, this transport system is intended to deliver as uniformly as possible the flux of fresh air into the gas exchange units located in the distal regions. At inspiration, the airways are opened by the respiratory muscles. At expiration, due to the pressure exerted by the diaphragm and the elastic energy stored in the respiratory muscles, the compliant properties of the airways play a major role. The flow pattern in the tree is then the result of a complex interplay between the flexible airway structure and the applied pressure distribution. In extreme conditions, as in forced expiration, the system exhibits non linearities that may lead to important inhomogeneities in the flow distribution. The flow is therefore a signature of the behavior of the compliant bronchial geometry.

Unfortunately, solving the coupled equations governing the flow in the entire tree and the fluid structure interaction in each bronchus is computationally out of reach. We present here an alternative model of the flow distribution into the tracheobronchial tree: first, the fluid-structure interaction at the bronchus level is modeled by compliance laws which relate the bronchus diameter to the transmural pressure (the pressure difference between the inside and the outside of the bronchus). Second, the pressure profile is computed by solving in each bronchus a 1D differential equation. To our knowledge, this model allows one to obtain for the first time in any bronchial tree, symmetric or not, the flow in each bronchus, up to the 15th generation at each step of the expiration [1]. Therefore, it is particularly adapted for studying the relationship between the mechanical properties of the airways at the elementary level, the geometry of the entire tree [2], and its global ventilation performance.

For a healthy bronchial tree, we recover the classical flow-volume curves with two characteristic parts: the first part is dependent of the patient’s effort and the second is linear with respect to the expired volume. Finally, several configurations and pathologies are explored, showing how the geometry and mechanics interplay to give rise to a global behavior.

[1] M. Florens, B. Sapoval, and M. Filoche, “The optimal branching asymmetry of a bidirectional distribution tree”, *Comput. Phys. Commun.*, doi:10.1016/j.cpc.2010.11.008.

[2] M. Florens, B. Sapoval, and M. Filoche, “An anatomical and functional model of the tracheobronchial tree”, *J. Appl. Physiol.*, doi:10.1152/japplphysiol.00984.2010.