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Personalized Pulmonary Poromechanics in Health and Idiopathic Pulmonary Fibrosis

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Abstract: Introduction. Lung biomechanics has been extensively studied by physiologists, experimentally as well as theoretically, laying the ground for our current fundamental understanding of the relationship between function and mechanical behavior. However, many questions remain, notably in the intricate coupling between the multiple parenchymal constituents. These fundamental questions represent real clinical challenges, as pulmonary diseases are an important health burden. Interstitial lung diseases, for instance, affect several million people globally. Idiopathic Pulmonary Fibrosis (IPF), notably, a progressive form of interstitial lung disease where some alveolar septa get thicker and stiffer while others get completely damaged, remains poorly understood, poorly diagnosed, and poorly treated [Nunes et al., 2015].

Methods. We recently developed a model of the lungs at the breathing time scale and the organ space scale [Patte et al., 2019], based on a general poromechanical formulation [Chapelle & Moireau, 2014], where the "solid" phase is composed of both tissue and blood while the fluid phase is the air. Several pulmonary-specific hypotheses have been formulated, notably that the end-inhalation and end-exhalation states are in static equilibrium. Moreover, specific boundary conditions are imposed on the lungs themselves, modeling the effect of diaphragm-induced loading and rib cage: a pressure applied on lung surface representing pleural pressure, and a frictionless contact with the moving thorax. Moreover, the constitutive behavior allows to reproduce the volumetric response of lungs to a change of pressure as observed in experimental data.

The proposed model can be personalized using clinical data [Patte et al., 2019]. From two 3D CT-scans, acquired at end-exhalation and at end-inhalation, we obtain a personalized geometry through image segmentation [Fetita et al., 2019]), a personalized porosity, personalized motion & boundary conditions

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through image registration [Genet et al., 2018]. Such data allow also to personalize regional mechanical parameters by minimizing the discrepancy between measured and computed motion.

Results. We will present results based on control and patient data. Notably, we will show that the model and estimation procedure can quantify the regional tissue stiffening induced by idiopathic pulmonary fibrosis.

Conclusion. Our results illustrate how our pulmonary poromechanical model can be used as a diagnosis tool in the clinic when it is personalized to a patient using clinical data acquired in standard protocols.

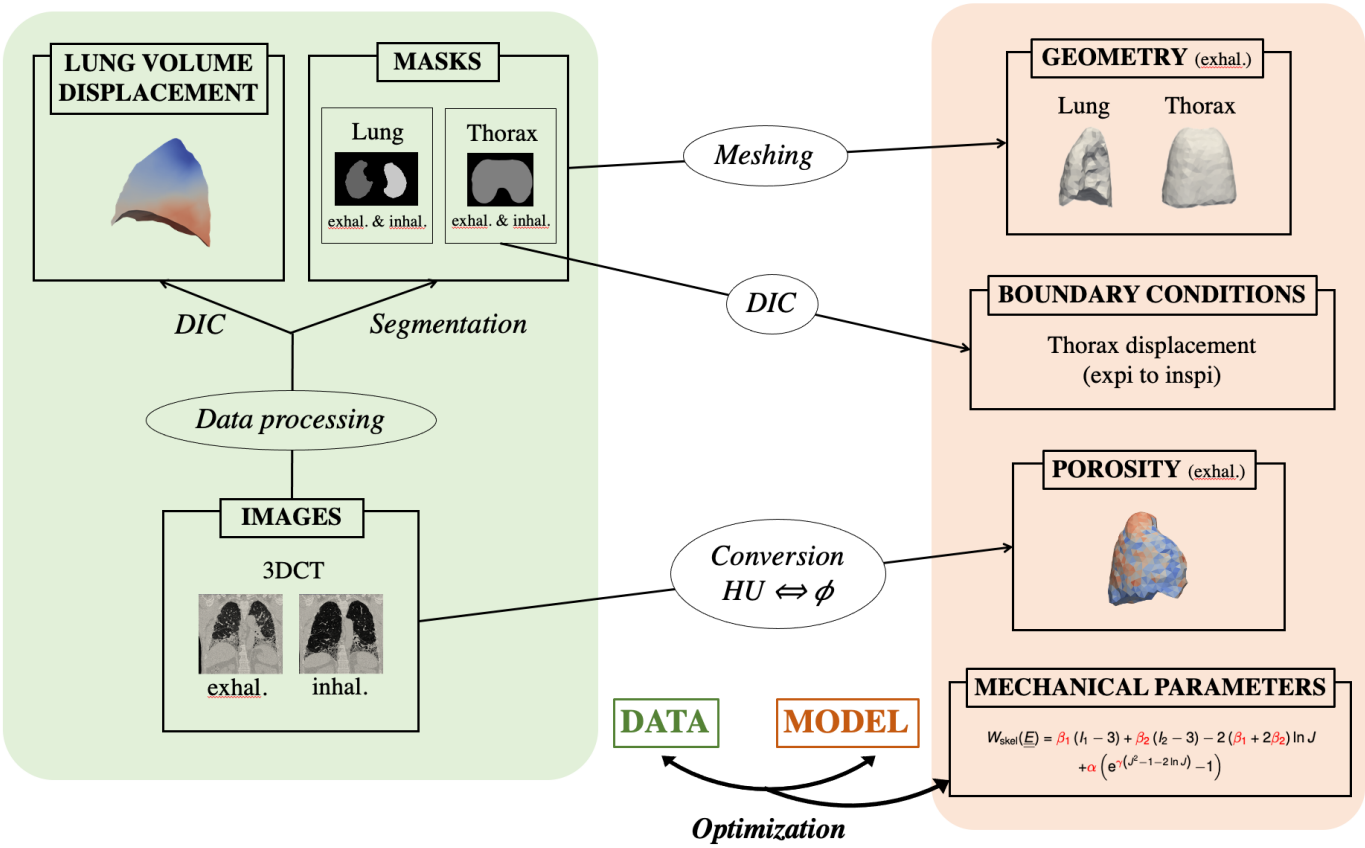

Figure Caption: Schematic of the proposed clinical image-based model personalization procedure.

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