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Computational Modelling of the Respiratory System: Discussion of Coupled Modelling Approaches and Two Recent Extensions

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Abstract

In this article we present advanced computational models of the respiratory system with a special focus on approaches that are able to tackle the interaction between flow and tissue components which is necessary to accurately represent the underlying physics of the lung. We review complexity of this new generation of so-called coupled models and present strategies for sensible and target-oriented dimensional reduction. From this inherent complexity it becomes clear that there is no ”one-size-fits-all” approach in the modelling of respiratory mechanics but one has to choose from a variety of different concepts to solve the problem at hand. We present four suitable coupled approaches introducing their underlying modelling idea and assumptions, their novelty against previous methods, possible scenarios of application, and limitations in a clinical practise. The quality of presented lung models is extended via regional validation against clinical measurements. This validation is performed using temporal highly resolved electrical impedance tomography monitoring. This detailed and for the first time dynamic regional validation generates further trust in the presented mathematically derived approaches. Finally the article closes with further steps towards simulation of gas exchange and local lung perfusion as the ultimate goal of respiratory modelling when ventilation is sufficiently understood.

Keywords: Respiratory mechanics, Fluid-structure interaction, Monolithic coupling, Reduced-dimensional modelling, Regional validation, Gas exchange

1. Introduction

The human respiratory system is a fascinating and at the same time a relatively young example of computational biomechanics and its application in medicine. Classical lung modelling approaches from a physiological/clinical perspective were until recently mainly limited to data-fitting of single compartment model parameters as e.g., described in [1, 2] rather than based on a sound mathematical formulation of the underlying physics of the organ at hand. From a mathematical perspective, however, the lung consists of a complex network of branching compliant tubes spanning a wide range of scales and flow regimes from almost laminar diffusion

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