Computational Modeling of Lung Epithelial Cell Deformation during the Opening of Compliant Airways

Xiaodong Chen¹ and Samir Ghadiali²,³

¹. Graduate Research Associate, Department of Mechanical Engineering, The Ohio State University, Columbus, Ohio, 43210 USA, e-mail: chen.1501@osu.edu
². Associate Professor, Department of Biomedical Engineering, The Ohio State University, Columbus, Ohio, 43210 USA, e-mail: ghadiali.1@osu.edu
³. Adjunct Professor, Department of Internal Medicine, Division of Pulmonary, Allergy, Critical Care and Sleep Medicine, Dorothy M. Davis Heart & Lung Research Institute, The Ohio State University, Columbus, Ohio, 43210 USA, e-mail: ghadiali.1@osu.edu

Patients with acute lung injury need to be treated with mechanical ventilators which generate microbubble flows in pulmonary airways. Unfortunately, experiments indicate that the mechanical forces generated during this process may cause significant cellular deformation and injury. In particular, previous studies, which cultured lung epithelial cells on rigid substrates, indicate that the large pressure gradients generated during microbubble flows is responsible for cellular injury. Recent experiments in our lab indicate that cells grown on a compliant gel substrate experience less injury than cells grown on a rigid substrate. We therefore hypothesized that the magnitude of the pressure gradient generated by microbubble flows may be lower in compliant airways compared to rigid airways. We have developed a fully coupled computational fluid-structure interaction model of microbubble flows in a compliant airway to test this hypothesis. We quantified how the pressure gradient varies as a function of wall stiffness and found that pressure gradients were largest on rigid walls. However, results also indicate that for the substrate stiffness values used in the experiments, the reduction in pressure gradient is minor and could not explain the reduced cellular injury observed on compliant substrates. We are currently developing alternative models to investigate the hypothesis that the compliant substrate “adsorbs” the pressure gradient forces generated by the microbubble and thus “shields” the cell from deformation and injury. We are also developing models that account for transient dynamics and 3D cell structure. Continued development of these models may help elucidate how changes in wall mechanics, as occurs during diseases like fibrosis or emphysema, influence cell injury during airway reopening. Supported by NSF grant 0852417.

Figure 1. Experiment setup for an air bubble propagation in a compliant airway.