Title: Toward a population-based analysis of aerosol delivery in the human lungs: image-based automatic mesh generation and numerical simulation

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Rationale: A multiscale computational framework for the human lungs consists of airway geometric modeling, image registration, computational fluid dynamics (CFD), and prediction of hot spots where inhaled aerosols could accumulate. This framework is essential to identify new sensitive structural and functional variables at local small scales in a subject-specific manner for distinguishing normal and diseased phenotypes. With sensitive discriminatory variables and associated phenotypes established, one could start to interrogate which phenotype, and subsequently individuals belong to this phenotype, is more susceptible to environmental risk factors. However, one of the challenges in applying the above framework from individual to population scales lies in construction of image-based three-dimensional (3D) subject-specific airway geometrical models and CFD meshes, which is very time-consuming. We proposed a method to automatically generate subject-specific airway models and meshes for CFD studies of aerosol delivery and structure-function (airway structure-hot spot) relationships in the human lungs.

Methods: The proposed method automatically expands computed tomography (CT)-based airway skeleton to generate the 3D centerline (CL)-based airway model, and then fit it to CT-segmented airways to generate the hybrid CL-CT-based model. The method was applied to 8 healthy and 16 severe asthmatic subjects for assessment of the accuracy of the airway models. We also developed a physiologically-consistent laryngeal geometrical model that can be attached to the trachea of the above models to produce a turbulent laryngeal jet. Gmsh was then applied to the laryngeal-airway models for automatic mesh generation. To assess the quality of CFD meshes, we compared the regional aerosol distributions in the human lungs predicted by the CL-CT-based models against those of the manually generated CT-based model. Results: The results show that the average geometric error associated with the proposed CL-CT-based model was 3.8% of the branch radius. The results also show that the aerosol deposition predicted by the hybrid CL-CT-based model is not significantly different from the prediction by the CT-based model with significance level of 10%.

Future work: The proposed CL-CT-based model can be potentially applied to study the structure-function relationships in a large population for phenotyping sub-populations of healthy and diseased lungs. With the assistance of statistical analysis and classification, one could begin to interrogate and identify sensitive variables in subpopulations along with genotypes for early detection of lung disease.

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